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Field water management studies using waters of different qualities and different leaching fractions showed that the soil in the project area has a high salt buffering capacity. The soil acted either as a source or a sink for salt depending on the leaching fraction and the quality of water used for irrigation. Minimum average leaching fractions attainable on a field scale were found to be controlled by the uniformity of irrigation water application.

Digital computer models were developed that consider properties of the soil, plant, water and environment. One model allows prediction of salt buildup and the yield response over several years. Salt buildup in the soil eventually caused a yield decrease. It was necessary to include a source-sink term in a salt flow model to accurately simulate field data. Source-sink phenomena observed in the field were confirmed by leaching tests conducted in the laboratory. Both models are potentially useful for salt management in the field.

Production functions were developed for dry matter and grain yields of corn for variable water and salt application. A relation between evapotranspiration and yield indicates that the osmotic effect of salt in the profile reduces evapotranspiration and, consequently, crop yields

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Management practices for control of quality and quantity of return subsurface flow were studied theoretically, in the laboratory, and full scale in the field.

Field water management studies using waters of different qualities and different leaching fractions showed that the soil in the project area has a high salt buffering capacity. The soil acted either as a source or a sink for salt depending on the leaching fraction and the quality of water used for irrigation. Minimum average leaching fractions attainable on a field scale were found to be controlled by the uniformity of irrigation water application.

Digital computer models were developed that consider properties of the soil, plant, water, and environment. One model allows prediction of salt buildup and the yield response over several years. Salt buildup in the soil eventually caused a yield decrease. It was necessary to include a source-sink term in a salt flow model to accurately simulate field data. Source-sink phenomena observed in the field were confirmed by leaching tests conducted in the laboratory. Both models are potentially useful for salt management in the field.

Production functions were developed for dry matter and grain yields of corn for variable water and salt application. A relation between evapotranspiration and yield indicates that the osmotic effect of salt in the profile reduces evapotranspiration and, consequently, crop yields.

The response of a given soil-water-plant system to management for the purposes of controlling quantity and quality of return flow depends on the physical and chemical character of the soil, as well as the management factors.

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LIST OF ABBREVIATIONS AND SYMBOLS

EC_{iw}	Electrical conductivity of irrigation water
EC	Electrical conductivity
EC_{dw}	Electrical conductivity of drainage water
LF	Leaching fraction
ET	Evapotransporation
E_{tp}	Maximum potential evapotranspiration
t'	Julian Calendar day for maximum evapotranspiration
Δt	Time interval in days
cw	Wind coefficient
Kc	Crop coefficient
$\frac{\Delta p}{\Delta Z}$	Hydraulic gradient
Z	Depth
M	Matric suction tensiometer reading
D_{dw}	Depth of drainage water
D_{iw}	Depth of irrigation water
C_u	Christiansen's coefficient of uniformity
ΣD	Sum of the absolute values of the deviations of the can-catches from the average catch.
C_{av}	Average can-catch
n	Number of catches
PE	Potential irrigation efficiency
C_{lq}	Average low quarter catch
D_a	Average depth applied
Du_{lq}	Low quarter distribution uniformity
Dc	Average depth caught
Du_{lc}	Low catch distribution uniformity
C_l	Low catch
C	Concentration
t	Time
D	Combined diffusion and hydrodynamic dispersion
q	Water flow
z	Depth
R	Soil solution concentration for no precipitation or dissolution
K	Coefficient of proportion
i	Subscript of depth increments

j	Subscript of time increment
s	Solid salt
Da	Depth applied
mb	millibars
ΔEC_{sw}	Change in electrical conductivity of the soil water
D_r	Depth of root zone
θ_{fc}	Water content by volume at field capacity
H_m	Lateral line inlet pressure
H_A	Average line pressure
R_n	Manifold headloss adjustment
EL	Change in elevation
H_D	Downstream end pressure
ΔH_m	Headloss in line
Q_A	Average sprinkler discharge
Q_D	Discharge of last sprinkler
Dm	Distance in meters
EC(4P)	Electrical conductivity measured with a 4-probe device
D_{ef}	Depth of effluent
EC_{ef}	Electrical conductivity of the effluent
Dp	Apparent diffusion coefficient
U	Interstitial velocity
λ	Transfer coefficient
ρ_b	Bulk density
θ_v	Water content by volume
S	Solid salts in milliequivalents per centimeter depth
K	Coefficient of Proportion
C_{ir}	Concentration of the influent water
ECC	Computed EC of the effluent
ECM	Measured EC of the effluent
Deff	Depth of effluent
T_s	Total salinity
D_o	Diffusivity at the surface $z = 0$
qo	Water flux at the surface $z = 0$
C_o	Concentration at the surface $z = 0$
C_{is}	Initial salinity
D	Average absolute deviation from M
M	Average depth of an ideal irrigation

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SECTION I

INTRODUCTION

Irrigation return flow is a large portion of the water influent to the streams and rivers of the Colorado River Basin. It is well documented (Utah State University, 1975) that salinity is the most serious water quality problem in the Basin. Indications of the importance of the problem are given in the report issued by U.S. Environmental Protection Agency (1971) entitled "The Mineral Quality Problem in the Colorado River Basin." Further indications are: the February, 1972 session of the Federal-State Enforcement Conference on the Colorado River held in Las Vegas; discussions of Colorado River salinity problems between the Presidents of the United States and Mexico; the new Western Regional Research Project entitled "Salinity Management of the Colorado River Basin" supported by the Agricultural Experiment Stations of the seven Basin states and the Cooperative State Research Service; and the National Conference on Managing Irrigated Agriculture to Improve Water Quality. At the present time, it is estimated that damages due to salinity amount to $230,000 per mg/l measured at Imperial Dam (Utah State University, 1975).

The consensus of present opinion is that salinity control in the Colorado River Basin may be accomplished in part by improvement of irrigation and drainage practices. Research work conducted by Utah State University (USU) under EPA grants WP-01492-01 (N)1, 13030 FDJ, and S-801040 (King and Hanks, 1975) indicated that there was considerable promise for exercising control of return flow quality by proper irrigation management. The basic premise underlying the total research effort in this direction has been that the soil profile above the water table can be used as a salt storage reservoir. Then, by proper management of irrigation, this salt may be held indefinitely or may be released by leaching only when desired. Recent work using greenhouse lysimeters at the United States Salinity Laboratory in Riverside, California, supports the idea of salt storage and indicates that very small leaching fractions can be used over extended periods of time without adversely affecting yield of crops (van Schilfgaarde, et al., 1974). Leaching percentages suggested may be as small as 1 to 3 percent. Previous work at Utah State University, cited above, also suggests that under certain conditions, salt may be precipitated and stored within the soil profile indefinitely without significant adverse effects on farming operations.

Inasmuch as the theory and laboratory tests indicate a high probability of success using irrigation management to control return flow quality and quantity, field studies were established to assess the feasibility of managing the soil profile as a salt storage reservoir. The research reported here gives the results of the field assessment. The experiment was designed to evaluate the importance of variables such as water table depth, salinity contents of applied water, and leaching fractions. The degree of control over irrigation applications necessary for management of the salt storage reservoir was evaluated. It was expected that techniques of irrigation scheduling could be developed to enable such irrigation management on a large scale. The data base developed extended improvement of mathematical models that are required to be used for efficient soil profile salinity management. The data collected and the models developed are to allow extrapolation of results to other conditions encountered in other irrigated areas. The research results should provide an improved basis for technical and economic evaluation of implementation of large-scale irrigation management for water quality improvement.

The field facilities for the research were provided by the previous research grants (King and Hanks, 1975). Additions of necessary sprinkler pipe to these research facilities were made for this study. Thus the research benefited from the initial investment to the original field facilities toward solving the problems of managing irrigation return flow quality.

A secondary benefit derived from the research was the training of scientific personnel in agricultural water quality management. Not only did personnel supported directly by the research grant benefit from the research experience, the facility provided research opportunities for students on traineeships under the EPA Training Grant #WP-213-05, T90060 with firsthand experience in dealing with real water quality problems. The experience thus gained provides trained personnel for entry into the water quality field or for consultation on water quality problems in the future.

The technique recently developed for determining crop production functions as influenced by soil-water and fertility levels were included in the investigation. This technique was used to determine crop production functions as influenced by soil-water and soil salinity levels. The technique is quite simple and inexpensive. It yields important information not currently available. Since crop production data can be converted to economic costs and returns, this information is basic to an economic evaluation of the effect of various salinity levels on crop production. Use of the production function technique was suggested by the very successful experiment developed to measure crop production functions as influenced by soil-water and fertility levels conducted over the last two years under the direction of R. J. Hanks and D. W. James of Utah State University (Bauder, Hanks and James, 1975). This experiment employed the continuous variable method in which a large number of water and fertility variables are employed in a sequence. Adjacent plots are not sufficiently different from their neighbors that borders are needed. Thus, the size of the plot is decreased from that required in conventional experiments with a corresponding increase in the number of variables that can be evaluated several times.

Inasmuch as field research on water management is expensive and time consuming, it was important to include laboratory tests and computer modeling components in the study. This balanced approach provides for maximum usefulness of the results obtained.

OBJECTIVES

The general objective of the research project was to develop a guide for farm management practices related to irrigation and drainage that could provide a method to exercise control over the quality and quantity of irrigation return flow. The concept of using the unsaturated zone above the water table as a salt storage reservoir was to be tested. Control of the mineral water quality (salinity) of subsurface irrigation return flows was the main objective of this work.

The specific objectives were:

1. To monitor the movement of water and dissolved salts within the soil profile above the water table, into the saturated zone, and into the tile drain effluent, under field conditions.
2. To field test the feasibility of using the unsaturated zone as a manageable salt reservoir under conditions of different salinity contents of applied water, different water table depths, and different leaching fractions.
3. To determine the effect on alfalfa yield of salt storage in the unsaturated zone as influenced by the variables of Objective 2.
4. To develop suitable irrigation scheduling techniques for effecting control over the quality and quantity of irrigation return flow.
5. To develop field methods for detection of soil water salinity changes suitable for evaluating the effectiveness of different irrigation management practices.
6. To further develop and verify management models (digital computer models) for describing the movement of water and dissolved salts in the soil profile to allow for extrapolation of the results obtained from the research area to other areas.
7. To determine crop production functions of corn and alfalfa as influenced by irrigation and salinity level.

SECTION II

SUMMARY AND CONCLUSIONS

IRRIGATION CONTROL FOR LOW LEACHING FRACTIONS

It has been shown that it is possible to control irrigation closely enough to maintain desired leaching fractions for small areas. However, the degree of control necessary to accomplish this on a commercial scale may not be feasible. For instance, this control was possible only by scheduling irrigations from lysimeter readings, and then only for select small areas. Also, for the system used on the water management plots, a variation of only 5 minutes in irrigation time could change a 3 percent leaching percentage to 4 percent for a 3-inch application. This is a 33 percent variation in leaching percentage, with only 1 percent variation in time.

EFFECT ON SALINITY PROFILES

For the particular conditions on the research farm, no significant change occurred in the salinity profiles for any of the treatments except for the lowest irrigation water quality treatment. For this treatment, the upper zones of the root zone became more saline for all leaching fractions. The expected change in root-zone salinity for each treatment as determined by a salt balance calculation for the conditions of each treatment was not achieved. The fact that the actual changes did not compare to the expected changes is attributed to the composition of the salts in the soil. Both the irrigation water and the soil solutions were high in calcium carbonate and calcium sulfate which are relatively insoluble. From the plot leaching trials, it appears that low leaching fractions cause precipitation of salts. This leads to the assumption that, at least for short periods of time, soil water salinity and drainage water salinity are relatively insensitive to management changes in leaching fractions for this particular soil and irrigation water.

IRRIGATION SCHEDULING AND MANAGEMENT

The Jensen irrigation scheduling computer program under-predicted ET for alfalfa by 16 percent when compared to measured ET when using weather data collected at the weather station in the alfalfa field. When temperatures from the nearby Vernal airport reporting station were used, the program still under-predicted ET by 8.6 percent. The program is calibrated for standard U.S. Weather Bureau reporting stations, thus, the justification for using Vernal airport data. This 8.6 percent error is considered to be as accurate as could be expected since the ET actually measured between two lysimeters varied 11.5 percent. The fact that the predicted ET for the two weather stations varied by 7.4 percent indicates the problem of choosing a single weather station location in an area and then extending the information collected at that station to other areas.

The technique of maintaining an irrigation interval of approximately 10 days seemed to work well for minimizing upward flow of water from the water table for the soils and depths to water table encountered in the study.

The irrigation scheduling and management techniques evaluated in this study may be workable tools for controlling the salinity of the root zone and thereby the salinity of the return flow only when combined with periodic field checks. Both soil moisture and soil salinity checks should be made periodically to evaluate the performance of the scheduling and management techniques used. Both checks should be done in areas that are expected to receive the least irrigation water. Determination of this location would require a detailed system evaluation.

SPRINKLER SYSTEM EVALUATION

The solid set sprinkler irrigation system evaluated had a very high uniformity and efficiency when evaluated over a full season. As expected, compositing the uniformity measurements over the season improved both uniformity and efficiency over that measured for a single irrigation. Alternate setting of the sprinkler lines every other irrigation also improved performance.

Under the best management conditions, the minimum average leaching percentage that the irrigation system was capable of accomplishing without under-irrigating some portion of the field was 10.3 percent. This leaching fraction must be added to any desired design leaching fraction to get the average leaching fraction necessary for the field in order to maintain the desired minimum leaching fraction on the least watered area. For the solid-set sprinkler system used on the farm, operated on an alternate set basis, the minimum leaching fraction attainable, without actually under-irrigating some area, is 10.3 percent. If some leaching fraction is maintained over all the area, 3 percent for example, then the minimum average leaching fraction required for the farm would be 13.3 percent.

The irrigation system tested was definitely above average in performance. It is expected that most systems would not be capable of this level of uniformity and control.

In general, it is unrealistic to expect to maintain average leaching percentages of less than 10 to 15 percent on a field scale under sprinkler irrigation. However, it is possible to maintain leaching percentages lower than normally attained in irrigated agriculture. If it is assumed that a previously recommended leaching percentage of 10 percent can now be reduced to 3 percent as the literature suggests, then this would result in a water savings equal to the difference in the two leaching percentages. This is due to the fact that the same conditions apply to the 10 percent leaching as to the 3 percent leaching. In other words, any minimum leaching fraction used must be applied to the least watered area, so reducing the minimum leaching requirement from 10 percent to 3 percent would result in a reduced average field leaching fraction no matter what the system uniformity.

LEACHING MODEL SIMULATION

Using a mathematical model that considers parameters relating the soil, water, plant and atmospheric system, and using the assumption that there is a direct relation between dry matter production and transpiration, the salinity effects due to osmotic potential were determined. The influence of initial soil salinity on model-predicted crop growth depended on root zone depth and irrigation management. Predictions made of the localized salt buildup in the root zone over a period of several years showed that some water management systems would produce high yields for several years before salt buildup would begin to decrease yields. Predictions verified that the influence of irrigation water application uniformity on salt buildup and yield reduction is significant.

Leaching trials conducted in the field and in the laboratory to study salt transport phenomena showed that when only mixing and displacement processes were accounted for, lower than expected salt concentrations of the soil solution were obtained when the influent was more concentrated than the original soil solution. When the influent was less concentrated than the soil solution, the measured concentration of the soil solution was higher than the expected. From the experimental results, it was concluded that incorporating the process of sink and source in a mathematical model that simulates salt movement could improve the predictive capabilities of the model. In determining the nature and effect of a "source-sink" term required in the model, several assumptions were made. It was assumed that the dissolution and precipitation played the main role in the source-sink processes. It was assumed that the rate of the process was directly proportional to the difference between the concentration of the surrounding solution and some concentration for which the rate was zero. And, it was assumed that the process was independent of the solid salt quantity as long as it existed in the soil unit.

The model was tested against laboratory data for steady and transient flow conditions. The model simulated the data reasonably well. The poorest agreement between the simulated and the measured curves occurred at the beginning of the leaching process.

The model was also tested against field data and was then integrated into a water flow model that provided water flow data. Two wetting cycles which differed in depth of water applied and irrigation water salt concentration were simulated in different ways. If the source-sink term was ignored, the model overestimated the salinity in the case where the electrical conductivity of the irrigation water (EC_{iw}) was greater than the initial EC of the soil solution. When the EC_{iw} was smaller than the initial EC of the soil solution, the salinity was underestimated.

When a source-sink term with uniform parameters for each profile depth increment was included, the average salinity of the profile was correct but the distribution from the average was still poor. When individually calibrated source-sink coefficients for each soil layer were fitted and assigned to each layer, a good simulation was achieved.

Thus the addition of a "source-sink" term to the model improved simulation of salt movement in the soil. The modification of the model has produced data which suggests that the level of prediction accuracy is approaching that useful for efficient irrigation management at the field level. Coefficients for the "source-sink" term can be easily obtained from field soil samples.

INFLUENCE OF SOIL SALINITY ON YIELD

The influence of salinity levels on the yield of corn showed an approximate linear decrease as salinity levels increased in studies at Logan and Vernal, Utah. Studies at Logan showed that the decrease was essentially due to the osmotic effect of the salt. The yield decreased because there was less water available for plant uptake and thus less soil water depletion. The results from Vernal showed the same trends but were confused by water flow upward from the water table in an unknown amount.

There was no influence of different applied salinity levels on the yield for alfalfa at Vernal, Utah, in 1975 studies. This was apparently due to presence of alfalfa roots below the zone of salinized soil. Thus, if plant roots are in salty and non-salty soil, and there is adequate water in the non-salty zone, it appears that there will be no yield reduction.

The influences of salinity on yield measured in the field can be accounted for with the model developed (Childs and Hanks, 1975). The model incorporated soil, water, plant and atmospheric influences to predict relative crop yield. Yield predictions assumed a direct relation between dry matter production and transpiration. The only salinity effect considered was osmotic potential. The influence of initial soil salinity on yield depended on crop type and irrigation management. Predictions made of salt buildup showed that some management systems would produce high yields for several years before salt accumulations would decrease yields. Predictions also showed that irrigation system uniformity could influence salt buildup and, therefore, yields.

SECTION III

RECOMMENDATIONS

1. Studies need to be made to determine the soil and water chemical properties that cause precipitation of salts to occur. There apparently are soil and irrigation water quality situations, like those found on the Vernal farm, where the buffering capacity of the soil causes leaching to be unnecessary for many years. Salts are apparently precipitated out, regardless of the leaching fraction, in a way which leaves the soil solution concentration relatively unchanged. This process can undoubtedly continue on for many years because it has been going on under irrigated conditions for many years. Thus it is apparent, under these conditions, that salts can be stored in the soil for many years before leaching is needed. Until that time, salts in the return flow are simply the product of the volume of drainage water and the soil solution concentration just above the drains. Studies are needed to determine how widespread the occurrence is in the Colorado River Basin.

2. Improved mathematical models need to be developed to incorporate the complex soil chemistry effects controlling source-sink behavior of soils so that accurate predictions can be made of the long-term effects of water management for control of the quality of return flow.

3. The use of an average leaching fraction below about 10 percent does not appear attainable under commercial sprinkler irrigation management practice. It would seem more practical to irrigate so that no leaching occurs for several seasons while monitoring the soil salinity status, and then leach periodically. This procedure would minimize salt flow to irrigation return flow during periods of low stream flow.

4. The model developed by Childs and Hanks (1975) to predict the influence of salinity on yield has been verified in the field. It will account for the osmotic effect of the salt, irrigation variations and water flow upward from a water table. It is recommended that this type of model be used to evaluate irrigation management systems as they relate to irrigation return flow and yield interactions. It is very important that these evaluations be done over several years' time because salinity buildup in a single year may not be significant.

5. It is suggested, based on model predictions, that it will be difficult to attain a low leaching fraction on a field basis where normal variation in applied irrigation water is encountered. It appears very reasonable to use the soil profile for storing salts for one to several years and to periodically leach the root zone.

6. The combined influence of salinity and water stress on yield can be accounted for by considering the combined osmotic and matric potential of the soil solution. Yield prediction is difficult where there is a

water table near the root zone that may have an influence on water availability. When there is a salinity variation in the plant root zone, it is recommended that root extraction be predicted based on the least saline zone (or the zone having the highest sum of matric and osmotic potential). Additional research is needed to determine the limits of partial root zone salination that can be tolerated by plants.

SECTION IV

METHODS

WATER MANAGEMENT EXPERIMENTS

The field research was conducted on a 53-acre (21 ha.) farm in the Ashley Valley near Vernal, Utah. The location of the farm relative to the city of Vernal is shown in Figure 1. The farm was operated by Utah State University as a research facility.

For the purposes of the water management study, twenty-seven plots were located in an established alfalfa field, Figure 2. The plots and treatments were selected to provide three depths to water table, three irrigation water qualities and three leaching fractions. Locations of other field experiments related to the interrelationship of soil salinity and water application are also shown in Figure 2.

Water Table Depths

The locations of the water management plots were such that nine plots lay in an area where the water table was 5 feet (1.5 m) or more below the surface, nine plots were where the water table was 7 feet (2.1 m) or more deep and nine plots were where the water table was 9 feet (2.7 m) or more below the surface. The locations of the particular areas of these depths to water table were determined from averages of piezometer data collected previously in 1971, 1972 and 1973.

Irrigation Water Qualities

The three different qualities of irrigation water used were available at the farm. The best quality water, about 0.8 mmho/cm, was delivered from the valley irrigation system into a small storage pond. The middle water quality, about 2 mmho/cm, was available from the Naples Drain. The low quality water, about 2.7 mmho/cm, was available from the South Tributary to the Naples Drain (see Figure 2). The actual salinity of the water sources varied with the area hydrologic conditions. Intermittent flow conditions made it necessary to construct a small storage reservoir on the South Tributary to the Naples Drain. Water was released from the reservoir as needed to supply the irrigation system pump during the required irrigation treatments.

Water was delivered to all the plots by sprinklers. Water for the 0.8 mmho/cm plots was obtained from the main irrigation supply and was delivered by the same electric motor driven irrigation pump used to irrigate the non-plot area of the farm. The water from the Naples Drain and the South Tributary was

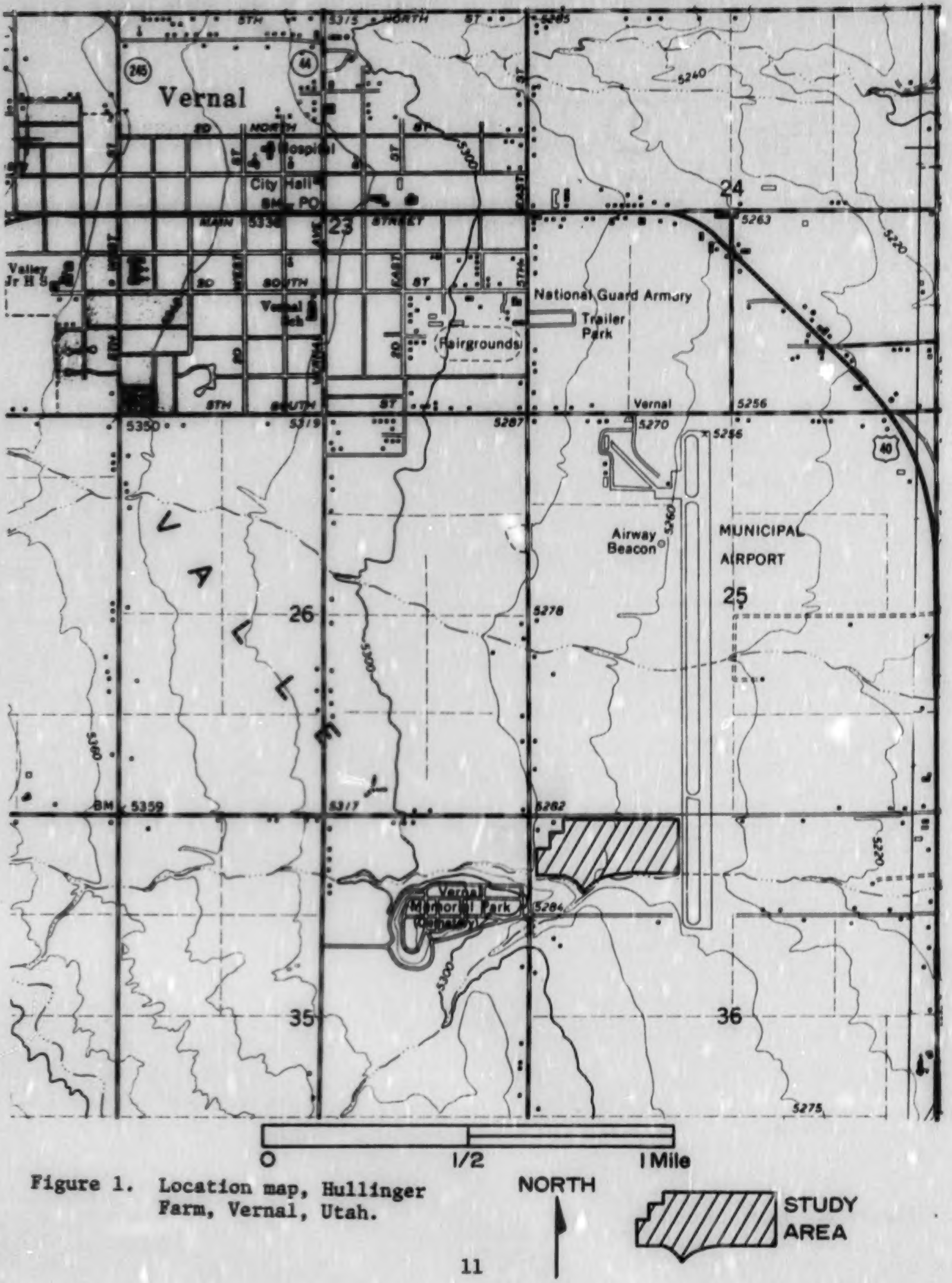
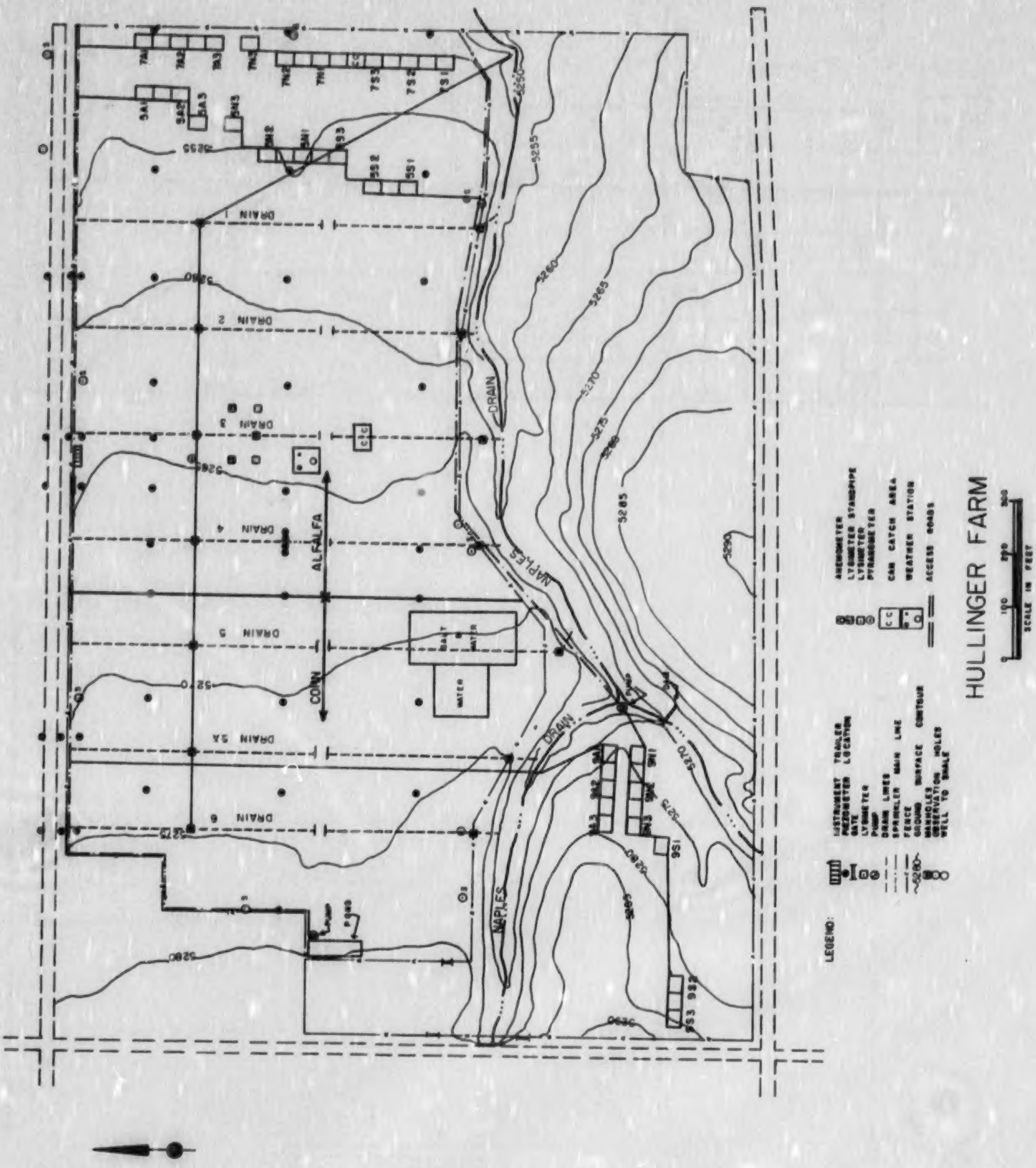

Vernal
5TH NORTH ST
5375
5285
2D NORTH ST
Hospital
City Hall
BM PO
MAIN 5336 STREET
23
24
5263
5240
5220
Valley Jr H S
2D SOUTH ST
Vernal Sch
National Guard Armory
Trailer Park
Fairgrounds
5TH SOUTH ST
5350
5319
5287
Vernal
5270
5256
40
Airway Beacon
5260
MUNICIPAL AIRPORT
25
26
5278
V A L L E Y
5300
BM 5359
5317
5282
Vernal Memorial Park Cemetery
5284
35
36
5275
0
1/2
1 Mile
NORTH
STUDY AREA

Figure 1. Location map, Hullinger Farm, Vernal, Utah.



HULLINGER FARM
LEGEND:
INSTRUMENT TRAILER
PIEZOMETER LOCATION
GATE
LYSIMETER
PUMP
DRAIN LINES
SPRINKLER MAIN LINE
FENCE
GROUND SURFACE CONTOUR
MANHOLES
OBSERVATION HOLES
WELL TO SHALE
ANEMOMETER
LYSIMETER STANDPIPE
LYSIMETER
PYRANOMETER
CAN CATCH AREA
WEATHER STATION
ACCESS ROADS
0
100
200
300
SCALE IN FEET
DRAIN 1
DRAIN 2
DRAIN 3
DRAIN 4
DRAIN 5
DRAIN 5A
DRAIN 6
NAPLES DRAIN
NAPLES
ALFALFA
CORN
WATER
5250
5255
5260
5265
5270
5275
5280
5285
5290

Figure 2. Farm layout.

delivered through a separate sprinkler system by a gasoline engine driven pump located at the junction of the two streams. The pump was so situated that the suction line could be transferred from one stream to the other to obtain the two different low quality waters without moving the pump.

Leaching Fractions

Three leaching fraction treatments were included in the experiment: zero leaching, and the calculated leaching fractions that would result in electrical conductivities at the bottom of the root zone of 8 and 25 mmhos/cm. The irrigation water applications were then determined from evapotranspiration and the desired treatment electrical conductivity of the drainage water by computing the required different leaching fractions for each water quality. The first treatment leaching fraction was zero, so the water applied was equal to evapotranspiration. The second and third treatment leaching fractions were calculated from an equation of the U.S. Salinity Laboratory (6):

$$LF = \frac{EC_{iw}}{EC_{dw}} \qquad [1]$$

where,

EC_{iw} = electrical conductivity of irrigation water

EC_{dw} = electrical conductivity of drainage water

LF = leaching fraction.

Table 1 gives the design EC_{dw}, EC_{iw} and the corresponding leaching fractions used in the study.

TABLE 1. DESIGN LEACHING FRACTIONS FOR WATER MANAGEMENT STUDIES

Design EC_{iw}	Design EC_{dw} *	Design EC_{dw} 25 mmho/cm	Design EC_{dw} 8 mmho/cm
	Leaching Fractions		
.8	0	.03	.10
2.0	0	.08	.25
2.7	0	.11	.34

*Designed for zero leaching, i.e., water application equal to evapotranspiration.

Plot Design

The water management plots were identified by a numeral, a letter, and a numeral. The first numeral indicated the depth to water table, 5, 7, or 9 ft (1.5, 2.1, or 2.7 m). The letter designated the water supply, using A for Ashley Creek (main water supply), N for Naples Drain, and S for South Tributary. The second numeral indicated the leaching fraction, 1 for zero leaching fraction, 2 for the middle leaching fraction and 3 for the high leaching fraction. For example, the plot for 5 ft (1.5 m) water table, best water quality, and lowest leaching fraction was designated 5A1.

Each plot was 25 ft x 30 ft (7.6 m x 9.1 m) with an area in the center of the plot 12 ft x 15 ft (3.7 m x 4.6 m) used for the study area (Figure 3). The instrumentation was placed along one edge of the study area so the instruments could be read without disturbing the crop in the study area. Each plot included the following equipment: (i) a piezometer to measure the depth to water table, (ii) a 2-in. (5 cm) diameter PVC neutron probe access tube with a ceramic cup sampler on the end set below the ground water depth to provide for both measurement of soil moisture content and sampling of the ground water, (iii) two tensiometers, one at 4 ft (1.2 m) and one at 5 ft (1.5 m) below the ground surface to determine the direction of vertical ground water flow, and (iv) soil solution samplers placed at 1 ft (0.3 m) intervals from 1 1/2 ft (0.46 m) below the ground surface to within 1 1/2 ft (0.46 m) of the expected high water table (5, 7, or 9 ft [1.5, 2.1, or 2.7 m]). Six of the zero leaching plots were equipped with barrel lysimeters as an added check on leaching fraction estimates.

ET Prediction and Scheduling

For evapotranspiration prediction and for an irrigation scheduling evaluation following the first irrigation season, climatological data from the on-farm weather station were analyzed using a computer program. The results obtained were compared to the measured evapotranspiration from the two hydraulic weighing lysimeters located in the field. The lysimeters used were the hydraulic weighing type described by Hanks and Shawcroft (1965). They were each 4 ft x 4 ft x 4 ft (1.22 x 1.22 x 1.22 m) fiberglass boxes with neutron access tubes and ceramic candle drains (see Figure 2 for location). The on-farm weather station consisted of an Eppley pyranometer connected to a strip chart recorder and integrator to give instantaneous intensity and integrated incoming solar radiation, a Class-A Weather Bureau evaporation pan, anemometers at two meters and pan height, a non-weighing rain gauge, maximum and minimum thermometers, wet and dry bulb thermometers, and a hygrothermograph for recording air temperature and relative humidity (see Figure 2 for location).

The computer program used was a modification of the program developed by Jensen (1969) and Jensen et al. (1970). The Jensen program was designed for irrigation scheduling and does not allow for the over-irrigation necessary to obtain controlled leaching fractions. The Jensen program assumes that the soil moisture depleted is exactly replaced. In order to extend this program for use in salinity control, it was necessary to make modifications

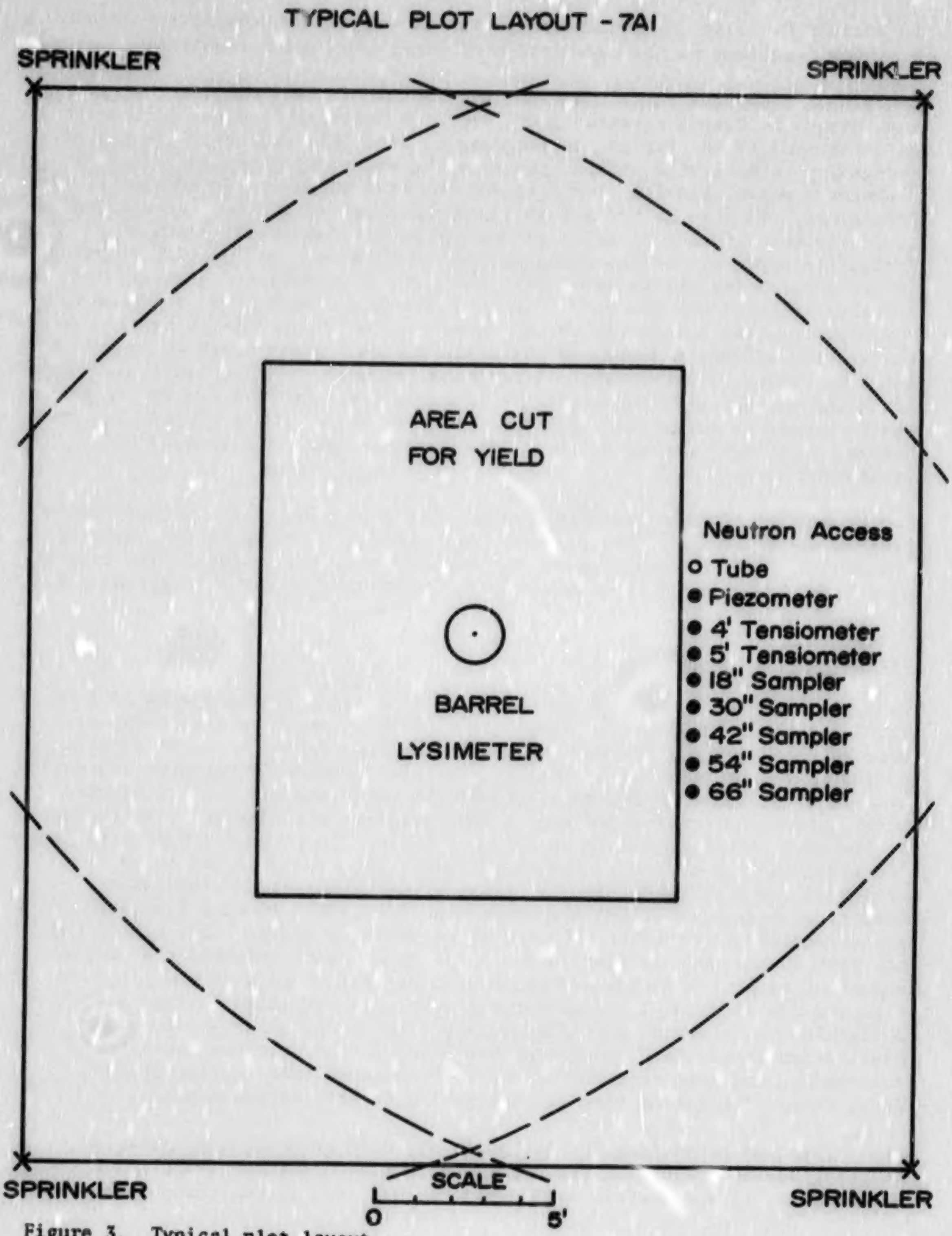

TYPICAL PLOT LAYOUT - 7A1
SPRINKLER
SPRINKLER
AREA CUT FOR YIELD
BARREL LYSIMETER
Neutron Access
○ Tube
● Piezometer
● 4' Tensiometer
● 5' Tensiometer
● 18" Sampler
● 30" Sampler
● 42" Sampler
● 54" Sampler
● 66" Sampler
SPRINKLER
SPRINKLER
SCALE
0
5'

Figure 3. Typical plot layout.

to account for over- and under-irrigation as well as to provide for including leaching fractions in the calculation of irrigation water required.

Since this study was conducted with sprinkler irrigation only, the program was changed to have a constant gross depth of water applied per irrigation as determined by the irrigation programmer. This allowed the frequency of irrigation to be varied without changing the gross depth applied. In the computer program, the leaching fraction for each field was determined by the programmer. To account for actual over- and under-irrigation, it would be necessary for a farmer to relay to the programmer the actual depth of irrigation applied. If the field was over irrigated, the leaching fraction in the program was set to zero until the planned accumulated seasonal leaching fraction was reached. Then the leaching fraction was returned to the predetermined scheduling value. Reducing the program leaching fraction, changed the allowable depletion, allowing the same gross depth to be applied. This, in effect, lengthened the irrigation interval. If the field was under-irrigated during any irrigation, the leaching fraction value in the program was increased to bring the field into balance by the next irrigation. This change, in effect, decreased the allowable depletion and decreased the irrigation interval.

For expediency in this comparison study, the disc storage feature of Jensen's program was taken out. For practical application it would be desirable to restore the disc storage included in Jensen's original program. The program used here, and a brief explanation of its operation is given in Appendix A.

Irrigation Practice

Each plot was irrigated by four #20 Hi-Lo Rainbird sprinklers with 5/32 in. (3.97 mm) nozzles located on each corner of the plot. The nozzle angles were adjusted to keep the water for one plot from reaching the study area of the next plot. The study area of each plot received water over its entire area from all four sprinklers. The sprinklers of the plots for a single water quality were all connected to the same line and operated simultaneously. At the base of each sprinkler was a gate valve. To allow for different leaching fractions and different sprinkler pressures, each plot had to be irrigated for a different length of time. All plots for a given water quality were started at the same time. As the lower leaching fraction plots received their water, the valves on those sprinklers were closed and the system continued to operate until all other plots received the proper amount of water. A single can-catch area was set up on a sample plot (see Figure 2 for location), and uniformity data were collected during each irrigation to determine the relationship between sprinkler pressure and application rate. Each irrigation was based on the previous can-catch information and then reevaluated for the can-catch taken during the irrigation. Irrigation time was controlled to the nearest minute.

The irrigation scheduling for the plots was done by using the hydraulic weighing lysimeters during the first year and by using pan evaporation the second year. The allowable soil depletion was kept as near as possible to

3.00 inches (76.2 mm) as indicated by the lysimeters. The non-weighing barrel lysimeters in the plots, measured with a neutron meter, were used as a check for under- or over-irrigation.

All plots were initially irrigated in the spring with the regular solid-set system used on the remainder of the field. At this time, the profile moisture content was assumed to be at field capacity, and the scheduling program for the treatment plots began.

System Evaluation

To provide for extension of the experience of the plot irrigations to field use, a separate can-catch was set up for the solid-set sprinkler irrigation system used on the farm. The farm system uses #30 WS TNT Rainbird sprinklers with 9/64 in. (3.57 mm) nozzles on a 30 ft x 50 ft (9.1 x 15.2 m) spacing. Four adjacent lines were operated at one time. A can-catch with a 5 ft (1.52 m) grid was set up in a clipped area of the alfalfa field (see Figure 2 for location). The depth of catch, wind movement, line pressure, sprinkler discharge, and evaporation were measured for each irrigation throughout the season. From this information, a precise field system evaluation was possible.

Salinity Monitoring

To monitor the change in salinity of the soil water and relate this change to the irrigation practice on the plots, salinity monitoring of both the irrigation water and the soil water was necessary. To effectively monitor the irrigation water, automatic water samplers were used during each irrigation. A sampler was mounted adjacent to the pump intake in each water supply. Prior to each irrigation, the samplers were charged by evacuating the sample bottles and closing the valves to hold the vacuum. During the irrigation, a clock tripped the valves at 2-hour intervals to give an even distribution of water samples over the period. Following each irrigation, the samples were removed and the electrical conductivity measured. One complete specific ion analysis was done on each irrigation supply during the season.

Following each irrigation, the soil solution samplers in the plots were evacuated with a hand pump and the vacuum was held over-night. The following day the samples in the tubes were collected and the electrical conductivities measured. The samples were taken at about the same time following each irrigation so the soils would be approximately the same moisture content at the time of sampling. As a check on the variation in moisture content, neutron probe readings were taken in the plots at the time of sampling. Once at the beginning of the season and once at the end of the season a complete specific ion analyses was done on the soil solution samples to determine the change in concentration of specific ions from the irrigation water to the soil water and from the beginning to the end of the season.

Soil Water Movement

To monitor the direction of vertical soil water movement in the unsaturated zone, the 4 ft (1.2 m) and 5 ft (1.5 m) tensiometers were read daily. From the tensiometer readings, the average hydraulic gradient between the two depths was calculated using the following relationship

$$\frac{\Delta P}{\Delta Z} = \frac{Z_2 + M_2 - (Z_1 + M_1)}{Z_2 - Z_1} \qquad [2]$$

Where

$\frac{\Delta P}{\Delta Z}$ = hydraulic gradient
Z_1 = depth of shallow tensiometer (cm)
Z_2 = depth of deep tensiometer (cm)
M_1 = matric suction reading of shallow tensiometer (cm of water)
M_2 = matric suction reading of deep tensiometer (cm of water)
$\frac{\Delta P}{\Delta Z}$ is positive when flow is downward

An attempt was made to maintain a downward gradient during the full season to prevent salt distribution in the soil profile by upward flow. Quantitative analysis of soil water flows would have required an accurate determination of the soil matric potential-hydraulic conductivity relationship for field conditions. This was not done since an accurate relationship would be very difficult to obtain under the heterogeneous soil conditions in the study area.

Piezometer readings were taken every other day to determine fluctuations in ground water levels throughout the season. These readings were necessary to determine the relationship between ground water depth and direction of soil water flow below the bottom of the root zone.

Actual Leaching Fractions

Since the distribution of water over the plot was not uniform, areas of interest in the plots did not necessarily receive a uniform amount of water. The two main areas of interest were the barrel lysimeter location and the soil solution extractor location in each plot. Irrigations on these exact locations were represented by averaging the water collected in the cans in the can-catch area which were in the same relative position as were the areas of interest in the plots. By this method, the seasonal water received by the lysimeter area and the sampling area of each plot was estimated.

The barrel lysimeters were used to estimate the actual leaching fraction for the plots the depth of drainage water collected in the lysimeter and the change in moisture content for each lysimeter was measured for the full season. By subtracting the depth of drainage and the change in moisture content (positive being an increase in moisture content) from the depth of water applied to the lysimeter, the ET for the plot was found. Since the sampling area was the area of interest for estimating the salt distribution-leaching fraction relationship, the ET for the plot was subtracted from the amount of water applied to the sampling area to arrive at the drainage water for the sampling area. The actual leaching fraction was determined from the following relationship:

$$LF = \frac{D_{dw}}{D_{iw}} \qquad [3]$$

where

LF = leaching fraction
D_{dw} = depth of drainage water
D_{iw} = depth of irrigation water

Since every plot did not contain a barrel lysimeter, the average ET for all plots was taken to be the same as the average of all the barrel lysimeter plots.

ET Prediction Analysis

For the purpose of measuring and predicting ET, climatological data and lysimeter data were collected daily throughout the growing season. However, when comparing lysimeter ET with pan evaporation and predicted ET from the irrigation scheduling program, cumulative values were used. As the lysimeter weight changes, the lysimeter moves up and down only slightly. As it moves, some binding and sticking occurs, resulting in reading fluctuations. The cumulative values tend to smooth out the fluctuations, since on a cumulative basis, a balance is maintained.

Irrigation System Uniformity Analysis

To relate the water application uniformity results obtained on the individual plots to actual field situations, an analysis of the performance of the standard sprinkler irrigation system was necessary as previously described. In order to evaluate the results of this analysis fully, several alternative procedures were examined.

First, the distribution uniformity of the system for each irrigation was estimated by Christiansen's coefficient of uniformity

$$Cu = 100 \left(1 - \frac{\Sigma D}{C_{av} \times n} \right) \qquad [4]$$

where

Cu = uniformity coefficient
ΣD = sum of the absolute values of the deviations of the catches from the average catch

C_{av} = average catch
n = number of catches

In addition to Cu, several other distribution calculations were made which included: potential irrigation efficiency, PE

$$PE = \frac{C_{1q}}{D_a} \times 100 \qquad [5]$$

where

PE = potential efficiency
C_{1q} = average low 1/4 catch
D_a = average depth applied

and, low 1/4 distribution uniformity, Du_{1q}

$$Du_{1q} = \frac{C_{1q}}{D_c} \times 100 \qquad [6]$$

where

Du_{1q} = low 1/4 distribution uniformity
D_c = average depth caught

and, minimum distribution uniformity, Du_{1c}

$$Du_{1c} = \frac{C_1}{D_c} \times 100 \qquad [7]$$

where

Du_{1c} = low catch distribution uniformity
C_1 = low catch
D_c = average depth caught

Second, the individual catches were progressively composited over the season to examine the "averaging" effect of long-term application. These composites were then evaluated by the same method as the individual tests.

Third, the catch data were theoretically superimposed to simulate an alternate setting pattern every other irrigation and were then composited. Alternate setting amounts to placing the sprinkler lines for each alternate irrigation midway between their position for the previous irrigation. Again, the evaluation was done as for the individual tests. These three sets of results were then compared to determine what improvement might be expected by following these management alternatives.

Crop Production as Influenced by Soil Salinity

The field work on crop production and soil salinity levels was conducted on the Hullinger experimental farm near Vernal, Utah. The farm was described in detail by King and Hanks (1973). A continuous variable plot design (Figure 4) replicated four times was established early in the spring of 1974. Each replication measured 50 x 100 feet (15.24 x 30.84 m) and included 10 salt treatments 10 feet (3.05 m) wide by 50 feet (15.24 m) long and 20 water treatments each 2.5 feet (0.76 m) wide by 100 feet (30.48 m) long. A single row of corn constituted a plot for a water treatment. Irrigation was accomplished approximately every 10 days through a line source sprinkler system as described by Hanks, Keller and Bauder (1974).

Corn (Utah hybrid 330) was first planted on May 22, but because of poor germination was replanted on June 13, 1974. The second planting, oriented about 6 inches (15 cm) to the side of the first, helped to increase the stand. After the two plantings, the corn was thinned to about 21,800 plants/acre (53,800 plants/ha.).

In 1974, $CaCl_2$ salt was applied with a 10-foot (3.0 m) wide fertilizer spreader pulled behind a tractor. The quantity of salt applied was determined by the osmotic potential desired for each treatment (Table 2). The spreader was calibrated to apply 3.4 pounds per acre (3.9 Kg/ha.) of salt, the amount required to obtain the osmotic potential of the first salt application treatment (S2). Each salt level thereafter required only additional passes by the tractor and spreader to obtain the desired salt application.

Initial intentions were to apply the salt in four applications and to disc the ground and irrigate to wet the soil to field capacity to a depth of six inches (15.2 cm). This procedure was designed to produce a uniform salinity in the top two feet (0.6 m) of soil. After the first application of water, it became obvious that it was impractical to add more water, get the tractor across the plots without getting stuck, and still complete the salt application in the time allowed. The following day the wet soil was disced and a second application of salt applied. The soil was then disced again, and with the spreader recalibrated for heavier application, the remaining salt was applied. Only after all the salt had been applied was the remaining water applied.

The water variable was obtained using Rainbird #30 sprinkler heads with a three-sixteenths inch (.48 cm) front nozzle and a three-thirty-second inch (.24 cm) rear nozzle with a 7 degree spreader slit. Two parallel irrigation lines consisted of 30 foot (9.14 m) sections of 3-inch (7.6 cm) aluminum irrigation pipe that were placed side-by-side to position a sprinkler every 15 feet (4.57 m). The high water treatment next to the water line was designed to receive about 1.5 times evapotranspiration, ET. ET was estimated from the two hydraulic weighing lysimeters located near the plot area (Figure 2) that were planted to alfalfa.

To determine the quantity of water being applied, a series of nine funnels mounted every 6 feet (1.8 m) on 3 inch (7.6 cm) aluminum irrigation pipe were

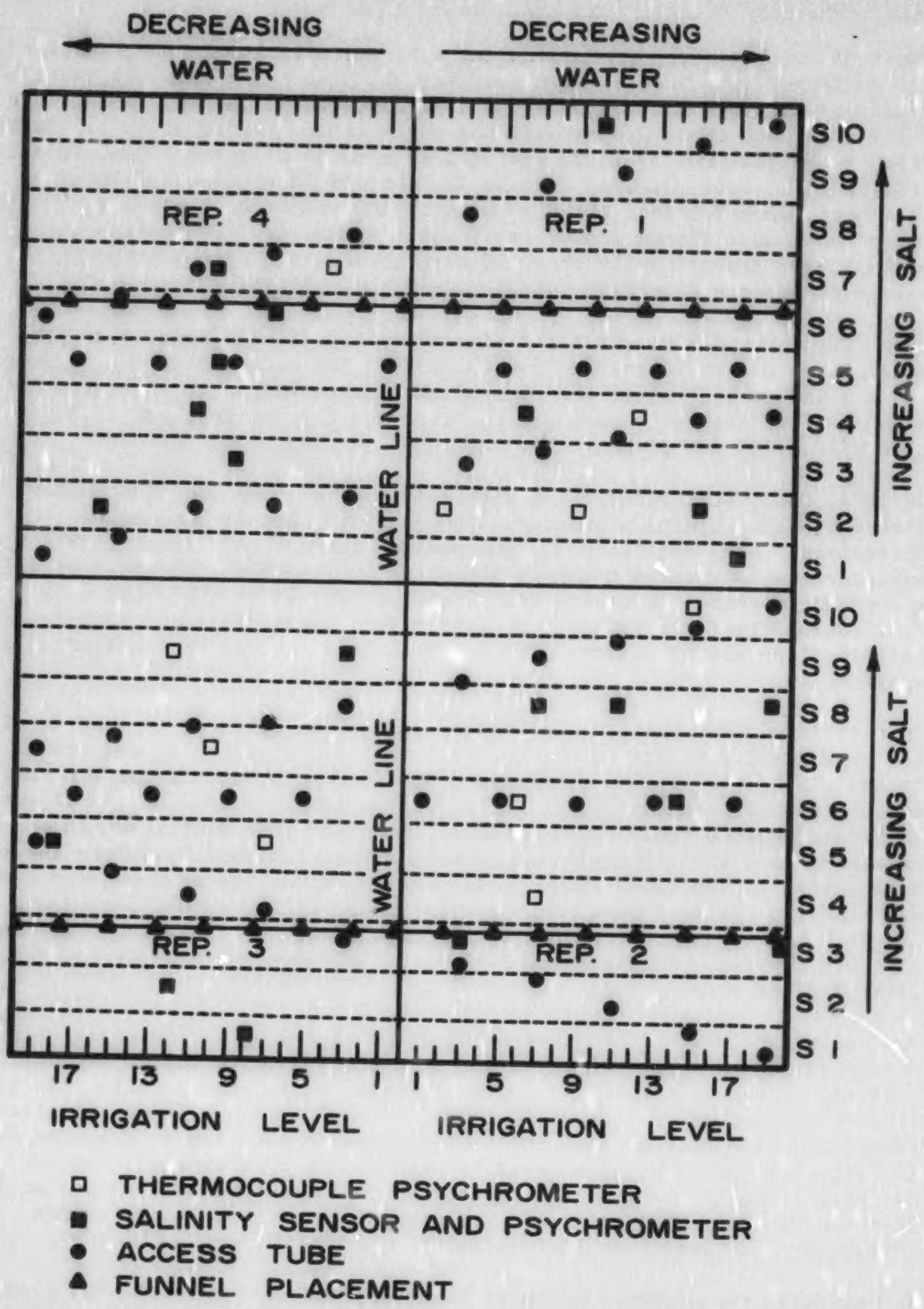

DECREASING
WATER
DECREASING
WATER
REP. 4
REP. 1
REP. 3
REP. 2
WATER LINE
WATER LINE
S 10
S 9
S 8
S 7
S 6
S 5
S 4
S 3
S 2
S 1
S 10
S 9
S 8
S 7
S 6
S 5
S 4
S 3
S 2
S 1
INCREASING SALT
INCREASING SALT
17
13
9
5
1
1
5
9
13
17
IRRIGATION LEVEL
IRRIGATION LEVEL
□ THERMOCOUPLE PSYCHROMETER
■ SALINITY SENSOR AND PSYCHROMETER
● ACCESS TUBE
▲ FUNNEL PLACEMENT

Figure 4. Continuous variable plot layout and instrumentation.

TABLE 2. OSMOTIC POTENTIAL OF THE SOIL SOLUTION AS A FUNCTION OF SALT LEVEL, DESIRED AND OBTAINED. (SOIL SAMPLES TAKEN 6-11-74)

Salt level	Osmotic Potential						
	Desired	Obtained					
	(bars)	(bars)					
		Depth-inches					
		0-6	6-12	12-18	18-24	24-36	36-48
S1	0.0	- 0.8	- 0.9	- 0.8	- 0.6	- 1.1	- 1.3
S2	- 0.5	- 0.8	- 1.0	- 1.5	- 1.7	- 1.2	- 1.2
S3	- 1.0	- 1.3	- 2.9	- 2.1	- 1.5	- 1.5	- 1.6
S4	- 1.5	- 1.4	- 2.8	- 2.7	- 1.4	- 1.3	- 1.3
S5	- 2.0	- 1.1	- 2.5	- 3.5	- 1.9	- 1.7	- 1.5
S6	- 2.5	- 1.4	- 3.3	- 4.2	- 2.2	- 1.4	- 2.3
S7	- 3.0	- 1.9	- 3.2	- 5.0	- 2.0	- 1.4	- 1.2
S8	- 5.0	- 4.8	- 6.0	- 4.5	- 2.1	- 1.1	- 1.2
S9	- 7.0	- 6.3	- 5.6	- 7.5	- 2.8	- 1.5	- 1.4
S10	- 9.0	-11.8	-12.8	- 5.2	- 2.4	- 1.7	- 1.6

used. A 4 inch (10.2 cm) diameter aluminum funnel was fitted snugly into the nine-sixteenth inch (1.4 cm) hole drilled into the funnel line pipe. To each funnel was connected a section of polyethylene tubing one-fourth inch (0.6 cm) inside diameter that ran through the length of the funnel line pipe and out of the plot area. The end of each tube was then connected to a 500 ml glass jar for collecting the water from each individual funnel. A number 11 rubber stopper with two 3-inch (7.6 cm) pieces of copper tubing mounted through it provided for air relief and the connection of the tubing to the jar. A slight slope on the funnel line pipe allowed most of the collected water to drain into the jars. It was necessary to use a hand vacuum system to extract all the water from the tubing for final measurement. The funnel line pipe was fastened to four lengths of three-quarter inch (1.9 cm) steel pipe driven vertically into the ground. This arrangement allowed the funnel precipitation collection system to be raised as the corn grew. The tops of the funnels were kept at the top of the corn. The funnel system allowed an accurate measure of the water being applied without entering the plot area. After an initial priming essentially all of the sprinkler water entering the funnel collection system could be extracted with the hand vacuum system.

In 1975 corn was again grown on the same plot with no additional salt added to determine if there were residual effects. Irrigation water was added in the same way as in 1974.

A similar study, applying various amounts of salt and water was also initiated in Vernal in 1975 on established alfalfa. Because of the difficulties encountered in applying the dry $CaCl_2$ in 1974, in 1975 salt was added as a solution with controlled concentrations. The treatments were established after the first crop of alfalfa was harvested in June. The number of treatments was reduced to 6 with equally spaced concentrations ranging from the normal irrigation water check to a solution with EC of 10 mmhos/cm (about -3.6 bars). It was originally intended to put on the water with a trickle irrigation system but the emitters clogged. A wooden dike was built to assist in a ponding type application. The infiltration rate of this soil was very high so the wooden dikes worked quite well. A line sprinkler water application system was then used during the season to apply irrigation water to the plots. About 10.2 inches (26 cm) of water was added to each plot in the salt application treatments which wetted the soil to about 35 inches (90 cm) depth.

A salinity-water application study was also established on corn at the Utah State University Greenville farm at Logan, Utah, in 1975. This was done to obtain a soil situation without a shallow water table that could supply water to the plant roots. The design of this experiment was similar to the alfalfa study at Vernal with 6 equal interval salinity treatments. The only difference between the two new 1975 experiments was that a mixture of salts was added to the soil at Logan whereas only $CaCl_2$ was used at Vernal. The mixture of salts used at Logan was chosen to approximate Colorado River water and was $CaCl_2$ (12 g), NaCl (6.2 g), Na_2SO_4 (3.9 g), and $MgSO_4 \cdot 7 H_2O$ (7.8 g). This mixture in 1 gallon (3785 cc) of water gave the highest treatment salt level of about 10 mmhos/cm (- 3.6 bars). In Logan about one foot (30 cm) of water was added to the soil with the salt application in mid-May. The water was applied using the trickle system. Water application took several days because of clogging of the emitters.

WATER MANAGEMENT MODEL WITH A SOURCE-SINK TERM

A field type water management model was developed in this study which deals with the simultaneous movement of water and salt in the soil. Other available models that consider only mixing and displacement processes during leaching usually overestimate the change in salinity of the soil solution for non-leached soils. Experience at several field locations (King and Hanks, 1975) showed that when water having either a higher or lower salt concentration than the soil solution was added to the soil, the resultant soil solution was changed very little. There appears to be a characteristic soil solution concentration that is unique to each section of the soil profile. The concentration in the soil solution is relatively unchanged when water of different concentrations is added. It was concluded that, in general, soil has a high "buffering capacity" that can be explained by dissolution and precipitation processes and that these processes would have to be accounted for in any model. The necessity of using a source-sink term in models of simultaneous salt and water movement in soil was suggested by Bresler and Hanks (1969) and by Childs (1975). Attempts to improve the predictions by including a "source-sink" term that used principles of solubility products and equilibrium exchange did not yield much improvement (Gupta, 1972). The use of the Gupta (1972) analysis considering primarily precipitation and solution of gypsum and calcite was insufficient to explain the field results. Apparently some mixture of impure magnesium and calcium sulfates was also involved. The chemistry of the soil solution is so undefined that it was decided that it could be best handled in the model by using a very general source-sink term. It was also decided that the dynamics of the process rather than equilibrium states should be accounted for. Combining mass flow and the diffusive flow and including a sink and source term gives a defining equation:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z} [D \frac{\partial C}{\partial z}] - \frac{\partial}{\partial z} (qC) + fn(C, z, t) \qquad [8]$$

where C is solution concentration, D is the combined diffusion and hydrodynamic dispersion, q is waterflux, z is depth, t is time and fn(C, z, t) is a function that represents sink and source due to ion exchange, precipitation and dissolution, adsorption, and changes due to chemical and biological activities.

In choosing the source-sink term, assumptions were made as follows:

1. The most important source-sink process is dissolution and precipitation.
2. The ion exchange process is of minor importance because the model treats the salt movement in terms of total salinity rather than in terms of the individual ion species; and the ion exchange capacity is relatively unaffected by salinity levels in this study.
3. Chemical changes due to biological activities are quantitatively small and considered negligible.
4. There is a characteristic concentration of the soil solution (R) at which there is no precipitation and no dissolution. This concentration is the saturation concentration relative to a given salt specie in mixtures of salt species. If (C) is greater than (R), precipitation will occur. If (R) is greater than the concentration of the soil solution (C), dissolution will occur as long as excess soluble salt in a solid state exists in the soil.
5. The specific surface of the solid phase compounds involved as a source or sink of salt is invariant.
6. The rate of the solution-dissolution process is directly proportional to the degree of departure from the equilibrium state.

As a result of the above assumptions, the term for fn(C,z,t) of equation [11] was assumed to be:

$$fn(C, z, t) = K(R - C) \qquad [9]$$

Where K is a coefficient of proportion related to the composite soil properties and salt composition. Substituting this term in equation [9] into the equation [8] of Warrick et al. (1971) gives:

$$\frac{\partial (C)}{\partial t} = \frac{\partial}{\partial z} \left(D_{(\theta,\, q)} \frac{\partial C}{\partial z}\right) - \frac{\partial\ (qC)}{\partial z} + K(R - C) \qquad [10]$$

where θ is the volumetric water content (fraction) and K = 0 when there are no solid phase salts present, i.e., there is no "source."

Note that when $R < C$ the source-sink term is negative indicating precipitation. When $R > C$ the term is positive, indicating dissolution.

The second order numerical approximation of the terms of [10] for non-equal space increments, using the Crank-Nicolson method (which reduces the $O(\Delta t)$ term to $O[(\Delta t)^2]$), (see Carnahan et al., 1967) is as follows:

$$\left(\frac{\partial\ (C\theta)}{\partial t}\right)_i^{j+\frac{1}{2}} = C_{i-1}^{j+1}\ (-AD) + C_i^{j+1}\left(\frac{\theta_i^{j+1}}{\Delta t} + AB + AD\right) + C_{i+1}^{j+1}\ (-AB)$$

$$+\ C_{i-1}^{j}\ (-AD) + C_i^{j}\left(AB + AD - \frac{\theta_i^{j}}{\Delta t}\right) + C_{i+1}^{j}\ (-AB)$$

where
$$A = \frac{\Delta t(\theta_i^{j+1} - \theta_i^{j}) \cdot (q_{i+\frac{1}{2}}^{j+\frac{1}{2}} + q_{i-\frac{1}{2}}^{j+\frac{1}{2}})}{8\ (\theta_i^{j+1} + \theta_i^{j}) \cdot \mathrm{DLXC}}$$

$$B = \frac{q_{i+\frac{1}{2}}^{j+\frac{1}{2}}}{\mathrm{DLXB}\ (\theta_i^{j+\frac{1}{2}} + \theta_{i+1}^{j+\frac{1}{2}}) \times 2}$$

$$D = \frac{q_{i-\frac{1}{2}}^{j+\frac{1}{2}}}{\mathrm{DLXA}\ (\theta_i^{j-\frac{1}{2}} + \theta_{i-1}^{j+\frac{1}{2}}) \times 2}$$

$$\frac{\partial}{\partial z}\left(D\ \frac{\partial C}{\partial z}\right)_i^{j+\frac{1}{2}} = C_{i-1}^{j+1}\ E + C_i^{j+\frac{1}{2}}\ (-E - F) + C_{i+1}^{j+1}\ F + C_{i-1}^{j}\ E + C_i^{j}\ (-E - F)$$

$$+\ C_{i+1}^{j}\ F$$

where $E = \frac{D^{j+\frac{1}{2}}_{i-\frac{1}{2}}}{2 \cdot DLXC \cdot DLXA}$; $F = \frac{D^{j+\frac{1}{2}}_{i+\frac{1}{2}}}{2 \cdot DLXC \cdot DLXB}$

$$\left(\frac{\partial\ (qC)}{\partial z}\right)^{j+\frac{1}{2}}_{i} = C^{j+1}_{i-1}\ (-H) + C^{j+1}_{i}\ (G - H) + C^{j+1}_{i+1}\ G + C^{j}_{i-1}\ (-H)$$

$$+ C^{j}_{i}\ (G - H) + C^{j}_{i+1}\ G$$

where $G = \frac{q^{j+\frac{1}{2}}_{i+1}}{4 \times DLXC}$; $H = \frac{q^{j+\frac{1}{2}}_{i-\frac{1}{2}}}{4 \times DLXC}$

$$K_1\ (R - C)^{j+\frac{1}{2}}_{i} = \frac{K_1}{2}\ (2R_i - C^{j}_{i} - C^{j+1}_{i}$$

Using these numerical approximations, the general equation becomes:

$$C^{j+1}_{i-1}\ \underbrace{(-H - AD - E)}_{a} + C^{j+1}_{i}\ \underbrace{\left(\frac{\theta^{j+1}_{i}}{\Delta t} + AB + AD + E + F + G - H\right)}_{b}$$

$$+ C^{j+1}_{i+1}\ \underbrace{(-AB - F + G)}_{c}$$

$$= \underbrace{C^{j}_{i-1}\ (AD + E + H) + C^{j}_{i}\ \left(\frac{\theta^{j}_{i}}{\Delta t} - AB - AD - E - F - G + H + P\right)}_{d}$$

$$+ \underbrace{C^{j}_{i+1}\ (AB + F - G) - RP}_{d}$$

where:

C is the concentration of the solution
i is the subscript for depth increment z
j is the superscript of time increment t

$DLXA = z_i - z_{i-1}$; $DLXB = z_{i+1} - z_i$; $DLXC = (z_{i+1} - z_{i-1})\ 1/2$

With specific boundary conditions imposed, n equations could be represented by a tridiagonal matrix that can be easily solved. The chosen boundary conditions must be specified. In addition to the computation of the concentration of the soil solution, a computation of the solid salt, s, was included as follows:

$$s^{j+1}_{i} = s^{j}_{i} - K(R - C^{j}_{i})\ \Delta t. \qquad [12]$$

The testing of the concept was done as follows:

1. R and K values were found and used to simulate measured data of breakthrough curves developed in leaching studies in a soil column.

2. The R and K values obtained were used to predict the salinity profiles in another separate soil column. The simulation allowed determination of the concentration of the soil solution, the soluble salts in the solid phase and the total salts.

3. Simulation of data obtained from a field leaching experiment was then used to verify the model.

WATER QUALITY EFFECTS ON TRANSPIRATION

Model Prediction of Salinity Effects on Crop Production Assuming No Source-Sink Terms

The model described by King and Hanks (1975) was tested to evaluate whether yield prediction is influenced by salinity. Figure 5 shows that an additional principle assumption made in the model, i.e., that relative dry matter yield (Y/Ymax) is directly related to relative transpiration (T/Tp), is approximately correct. The model was used to evaluate crop yields where there were different salinity levels within the root profile. The model was also used to evaluate extraction of water from different sections of the root zone irrigated with saline water. Comparison of the computed data (Figure 6) shows good agreement with measured data from Lunin and Gallatin (1965) and Bingham and Garber (1970). In all cases computed transpiration from the saline soil profile sections was slightly less than that measured. Thus it appears that the model accounts for the effects of salinity on transpiration (and thus dry matter production) and will be useful for predicting the effect of salinity on crop yields.

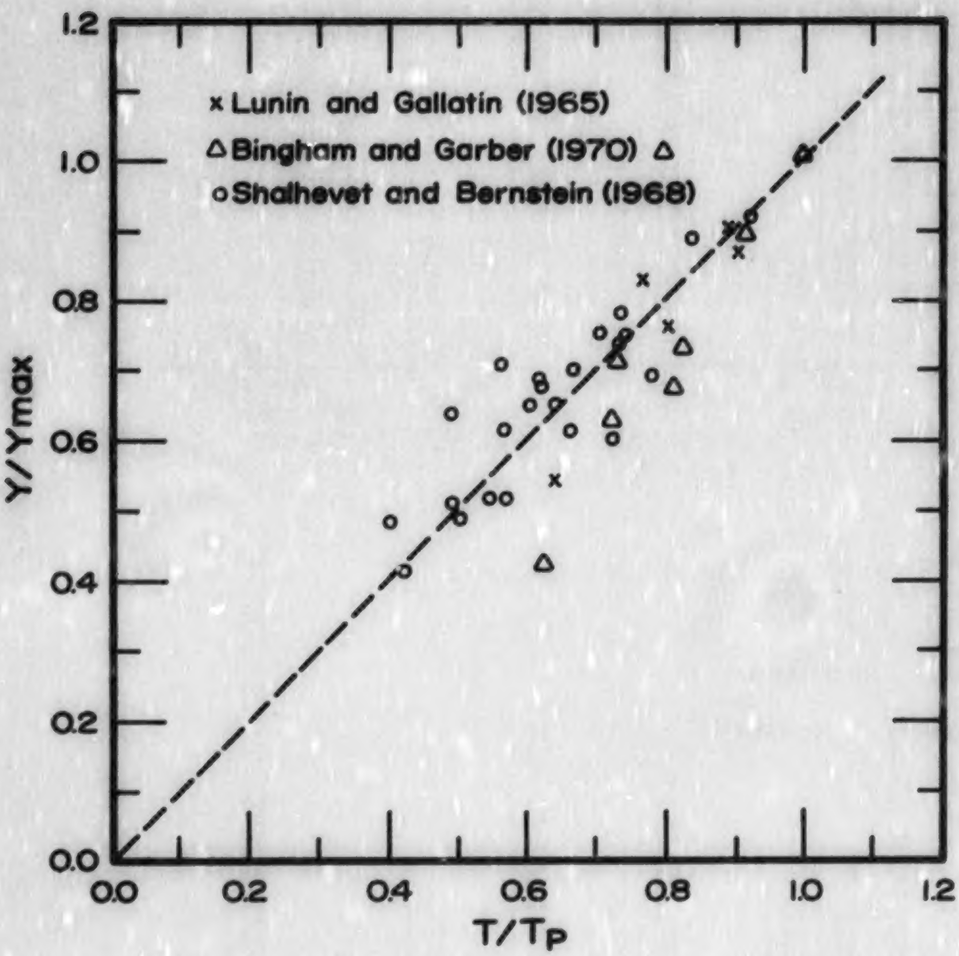


Figure 5. Relative yield as related to relative evapotranspiration under various saline conditions.

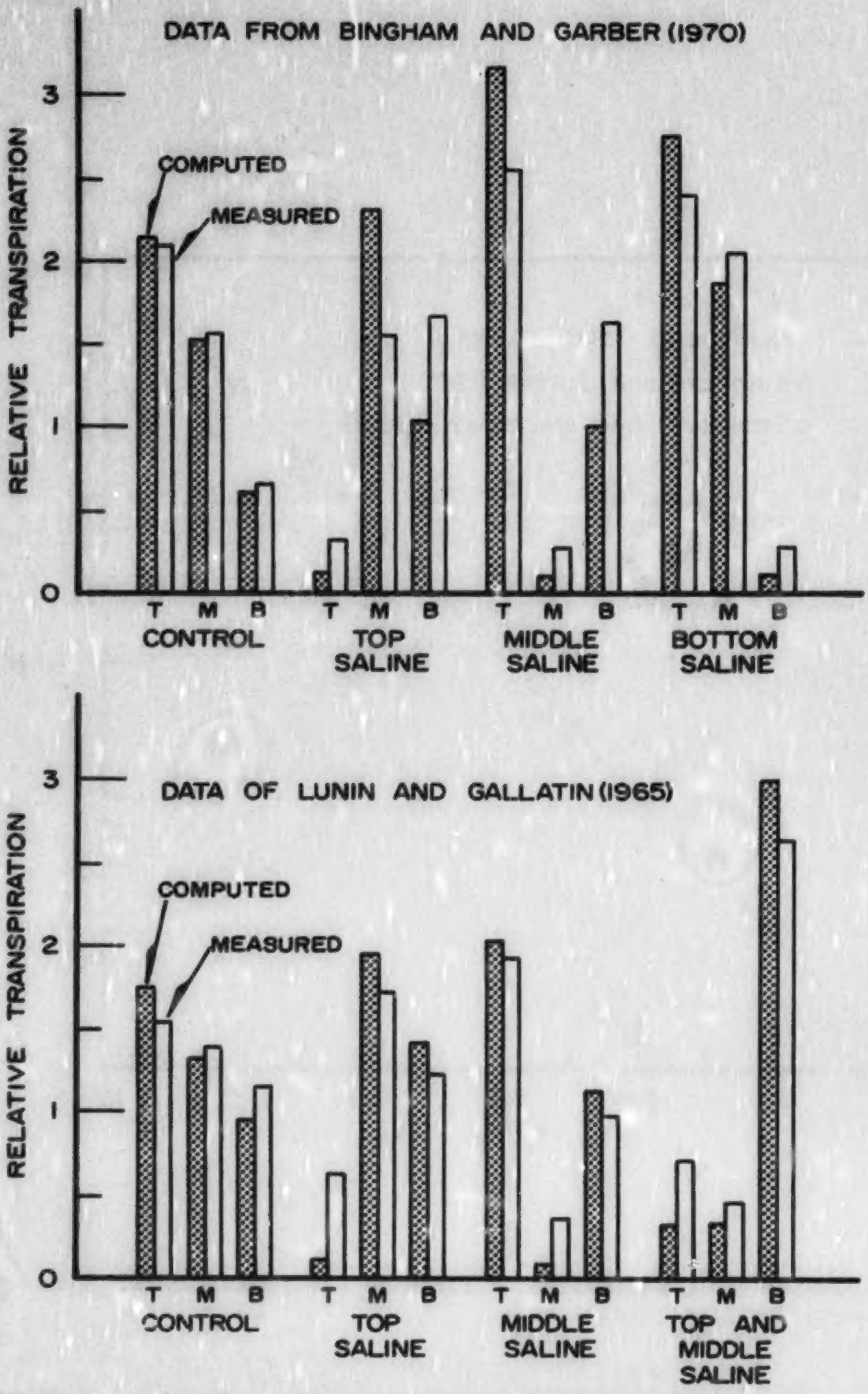


Figure 6. Comparison of measured and computed transpiration where different sections of the root zone were irrigated with saline water. T is top, M is middle and B is the bottom section.

SECTION V

RESULTS AND DISCUSSION

WATER MANAGEMENT AND LEACHING UNDER FIELD CONDITIONS

Plot Irrigation

The plot irrigation was scheduled from the lysimeter information shown in Table 3. Table 3 gives the cumulative measured hydraulic lysimeter ET less rainfall in inches for the period May 12, 1974 to August 26, 1974. This was the period over which the plots were studied. On May 12, the beginning date, the soil moisture depletion was assumed to be the season reference.

A soil moisture depletion of approximately 3.0 inches (7.6 cm) was allowed between irrigations. The plots were irrigated so that the 12 ft by 15 ft (3.6 x 4.6 m) study area in each plot received an average depth of water determined by:

$$D_a = \frac{ET}{1.0 - LF} \qquad [13]$$

where

D_a - depth applied
ET = evapotranspiration for irrigation interval
LF = leaching fraction for the treatment water quality.

Table 4 shows cumulative ET calculated from evaporation pan readings in 1975. The lysimeters became inoperative over the winter and could not be used in 1975. The computed ET values were therefore used to control irrigation during the 1975 season.

The average depth of water applied by the sprinkler system each irrigation was determined from the can-catch area data taken in the sample plot. Figures 7 and 8 show the relative composite can-catch for the two seasons. The average depth applied to the study area was taken as the average of the catch in the twelve interior cans. This average was used to determine the application rate for each plot by dividing the depth applied by the operation time and using the pressure-discharge curve in Figure 9 to adjust the water application time for changes in sprinkler pressure.

Table 5 contains the 1974 plot irrigation schedule giving the average-accumulated depth applied to the study area of each plot at the end of each irrigation. The desired depth of application was not necessarily applied each individual irrigation, but the cumulative depth for the season was very close to the desired application depth. In other words, the exact leaching fraction was not reached each irrigation, but the seasonal leaching fraction was near the desired value.

TABLE 3. CUMULATIVE HYDRAULIC LYSIMETER ET LESS RAIN FOR ALFALFA AT VERNAL, UTAH, MAY 12 TO AUGUST 26, 1974

Date	Cu. ET Less Rain (in.)[1]	Date	ET Less Rain (in.)	Date	ET Less Rain (in.)
5/12	.13	6/17	9.02	7/23	18.95
13	.42	18	9.15	24	18.90
14	.75	19	9.36	25	18.90
15	1.01	20	9.61	26	19.06
16	1.33	21	9.93	27	19.22
17	1.57	22	10.19	28	19.36
18	1.82	23	10.48	29	19.62
19	2.12	24	10.42	30	19.90
20	2.46	25	10.84	31	20.01
21	2.63	26	11.08	8/01	20.26
22	2.78	27	11.43	2	20.51
23	3.01	28	11.83	3	20.68
24	3.20	29	12.14	4	20.94
25	3.46	30	12.44	5	21.14
26	3.64	7/01	12.90	6	21.36
27	3.85	2	13.36	7	21.68
28	4.14	3	13.66	8	22.00
29	4.42	4	13.94	9	22.20
30	4.87	5	13.69	10	22.48
31	5.26	6	14.20	11	22.62
6/01	5.60	7	14.36	12	23.04
2	5.87	8	14.65	13	23.26
3	6.16	9	14.98	14	23.635
4	6.34	10	15.29	15	24.12
5	6.98	11	15.64	16	24.39
6	7.60	12	16.06	17	25.02
7	7.46	13	16.34	18	25.00
8	7.46	14	16.60	19	25.33
9	7.72	15	16.91	20	26.62
10	7.88	16	16.97	21	25.92
11	8.00	17	17.15	22	26.16
12	8.17	18	17.435	23	26.46
13	8.36	19	17.880	24	26.70
14	8.60	20	18.10	25	26.93
15	8.79	21	18.31	26	27.17
16	8.96	22	18.57	27	27.37

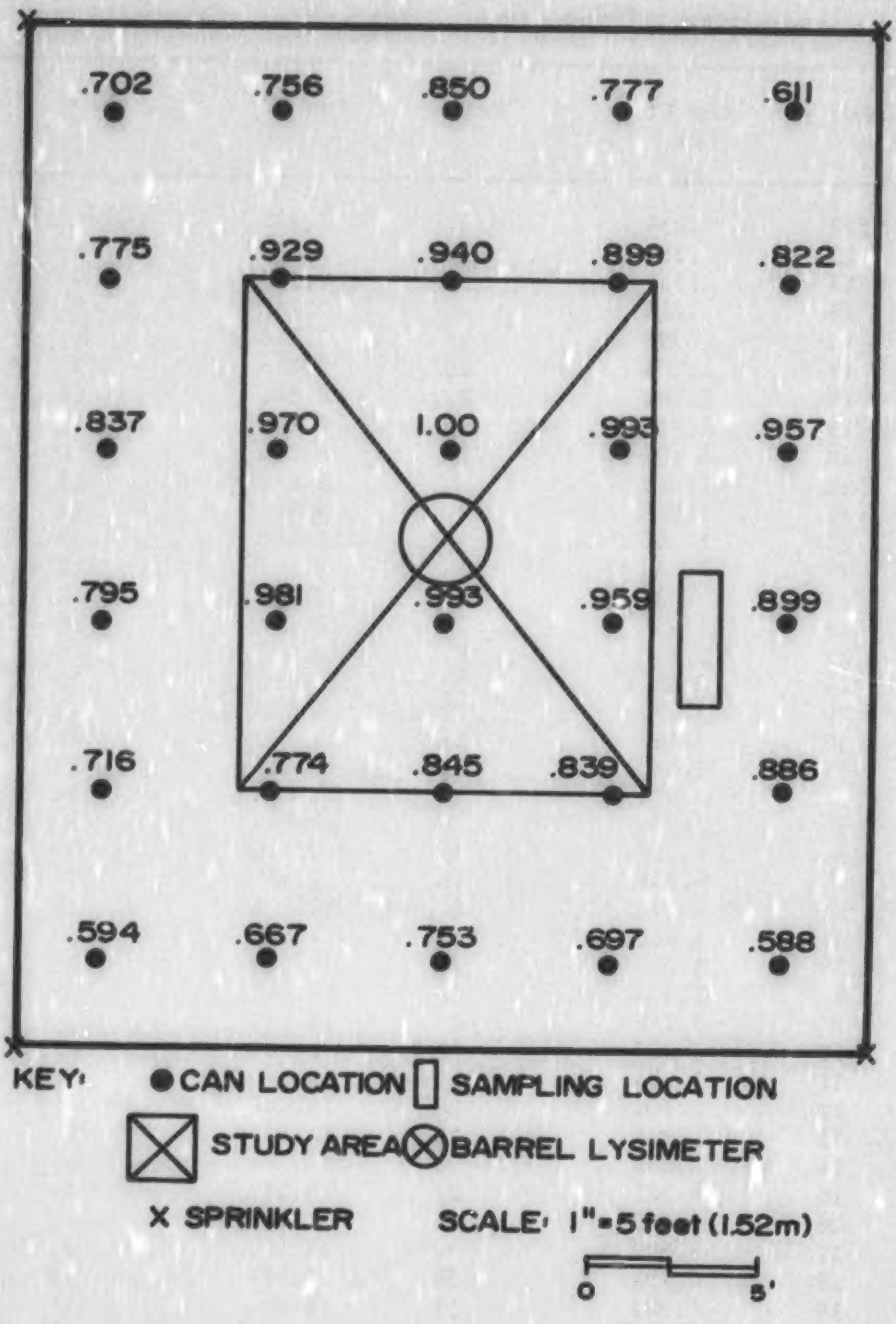
---

[1] 1 inch = 2.54 cm

TABLE 4. CUMULATIVE ET, MAY 12 TO SEPTEMBER 13, 1975, CALCULATED FROM CLASS A PAN

Date	Cum ET (in.)	Date	Cum ET (in.)	Date	Cum ET (in.)
5/12	.234	6/23	7.328	8/4	17.092
13	.356	24	7.479	5	17.317
14	.558	25	7.560	6	17.714
15	.776	26	7.782	7	18.150
16	.999	27	7.878	8	18.513
17	1.154	28	8.068	9	18.802
18	1.242	29	8.146	10	19.005
19	1.356	30	8.146	11	19.178
20	1.602	7/1	8.286	12	19.392
21	1.675	2	8.640	13	19.746
22	1.885	3	8.997	14	19.915
23	2.092	4	9.283	15	20.126
24	2.234	5	9.667	16	20.358
25	2.434	6	9.854	17	20.599
26	2.636	7	10.205	18	20.895
27	2.797	8	10.447	19	21.077
28	2.887	9	10.693	20	21.163
29	3.053	10	10.915	21	21.442
30	3.167	11	11.203	22	21.632
31	3.332	12	11.464	23	21.879
6/1	3.470	13	11.743	24	22.170
2	3.904	14	11.948	25	22.375
3	4.368	15	12.110	26	22.525
4	4.554	16	12.361	27	22.636
5	4.776	17	12.571	28	22.844
6	4.965	18	12.830	29	23.008
7	5.034	19	13.006	30	23.175
8	5.132	20	13.246	31	23.354
9	5.112	21	13.430	9/1	23.492
10	5.302	22	13.738	2	23.589
11	5.554	23	13.975	3	23.759
12	5.706	24	14.246	4	23.837
13	5.938	25	14.507	5	23.966
14	6.166	26	14.784	6	24.088
15	6.382	27	15.051	7	24.204
16	6.652	28	15.282	8	24.298
17	6.692	29	15.449	9	24.447
18	6.798	30	15.689	10	24.541
19	6.882	31	15.912	11	24.660
20	6.884	8/1	16.184	12	24.782
21	7.046	2	16.482	13	24.902
22	7.179	3	16.756		

1/ 1 inch = 2.54 cm.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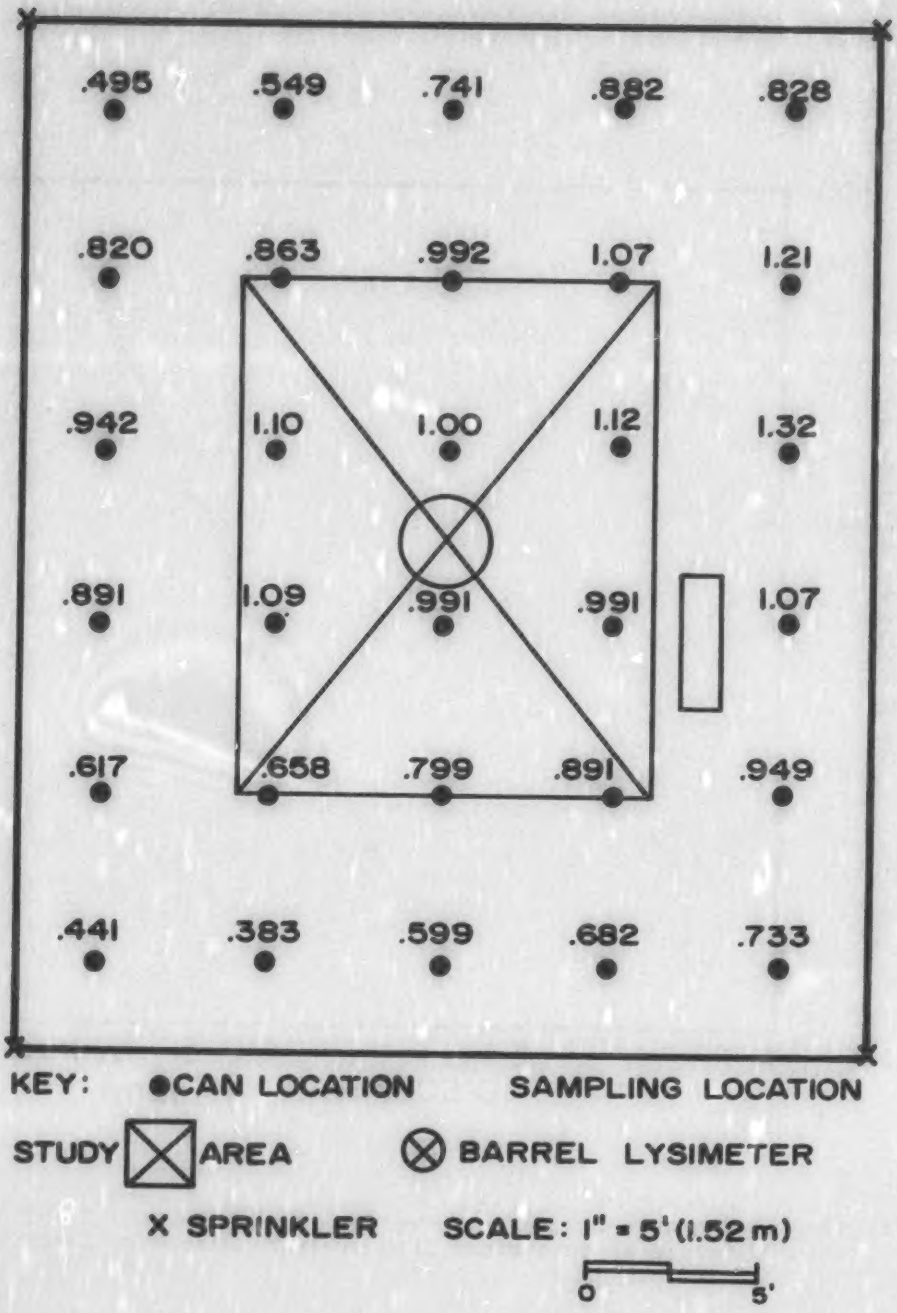
KEY:
● CAN LOCATION
▯ SAMPLING LOCATION
☒ STUDY AREA
⊗ BARREL LYSIMETER
X SPRINKLER
SCALE: 1" = 5 feet (1.52m)
0
5'

Figure 7. Relative composite can-catch for sample plot, 1974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KEY: ● CAN LOCATION
SAMPLING LOCATION
STUDY AREA
BARREL LYSIMETER
X SPRINKLER
SCALE: 1" = 5' (1.52 m)
0
5'

Figure 8. Relative composite can-catch for sample plot, 1975.

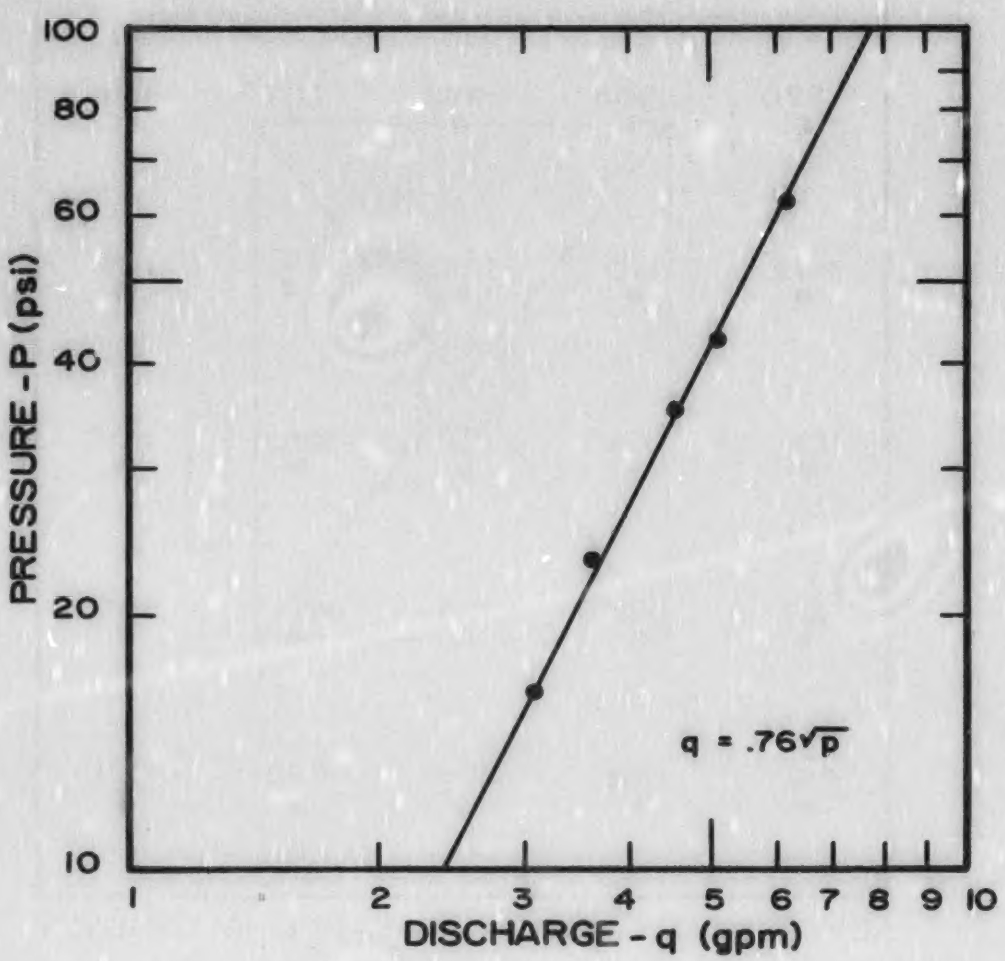

Figure 9. Pressure-discharge curve for 5/32" (0.40 cm) lo-hi nozzle as determined from pressure-discharge tests.

TABLE 5. 1974 IRRIGATION SCHEDULE GIVING DATES AND CUMULATIVE DEPTHS APPLIED FOR 27 INDIVIDUAL PLOTS USED IN THE STUDY

	Date						
Plot	6/5 - 6/7	6/22 - 6/24	7/4 - 7/6	7/15 - 7/17	7/31 - 8/2	8/12 - 8/13	8/26 - 8/27
	Cumulative Depth Applied (in.)[1]						
5A1	6.80	9.75	13.47	17.02	19.72	22.56	27.19
7A1	6.80	10.20	13.42	16.93	19.76	22.56	27.19
9A1	5.44	9.03	12.81	17.05	19.73	22.71	26.95
5N1	6.12	9.22	13.65	16.94	20.05	22.50	27.11
7N1	6.12	9.22	13.69	19.99	20.02	22.62	27.08
9N1	5.44	8.84	13.52	17.04	19.79	22.48	27.07
5S1	6.12	9.22	13.54	16.92	19.87	22.50	27.13
7S1	6.12	9.26	13.65	16.91	19.79	22.56	27.11
9S1	5.44	9.15	13.55	16.86	19.85	22.52	27.03
5A2	6.90	9.94	13.96	17.51	20.35	23.26	28.03
7A2	6.90	10.40	13.87	17.41	20.37	23.25	28.00
9A2	5.52	9.20	13.63	17.69	20.37	23.25	27.78
5N2	6.60	9.88	14.86	18.44	21.52	24.50	29.45
7N2	6.60	9.88	14.92	18.45	21.40	24.62	29.41
9N2	5.87	9.49	14.89	18.85	21.48	24.54	29.40
5S2	6.79	10.27	14.62	19.08	22.34	25.28	30.49
7S2	6.79	10.31	14.83	18.93	22.15	25.35	30.47
9S2	6.04	10.39	14.96	18.93	22.30	25.26	30.48
5A3	7.47	10.77	15.01	18.87	21.91	25.03	30.30
7A3	7.47	11.28	14.91	18.79	21.96	25.06	30.17
9A3	5.98	9.96	14.97	19.12	21.94	25.06	29.89
5N3	7.64	11.89	17.66	22.59	26.42	29.99	36.15
7N3	7.64	11.89	17.71	22.73	26.27	30.08	36.08
9N3	6.79	11.30	18.06	22.68	26.38	29.97	36.20
5S3	8.19	13.42	18.85	25.78	30.19	34.11	41.12
7S3	8.19	13.42	19.64	25.58	29.78	34.20	41.07
9S3	7.28	12.17	18.86	25.61	30.04	34.05	41.11

[1] 1 inch = 2.54 cm.

TABLE 6. 1975 IRRIGATION SCHEDULE GIVING DATES AND CUMULATIVE DEPTHS APPLIED FOR 18 INDIVIDUAL PLOTS[1] USED IN THE STUDY

	Dates		
Plot	7-9	7-21 8-7 8-8	8-13 8-14
	Cumulative Depth Applied (in.)[2]		
5A1	4.03	6.19	9.75
7A1	4.03	6.19	9.84
5N1	4.03	7.97	10.45
7N1	4.03	8.08	10.70
5S1	4.03	5.92	8.72
7S1	4.03	5.97	8.83
5A2	4.03	6.37	10.08
7A2	4.03	6.38	10.11
5N2	4.03	8.11	10.63
7N2	4.03	8.20	10.87
5S2	4.03	6.03	8.86
7S2	4.03	6.07	9.02
5A3	4.03	6.43	10.16
7A3	4.03	6.51	10.25
5N3	4.03	8.39	10.91
7N3	4.03	8.58	11.29
5S3	4.03	6.21	9.10
7S3	4.03	6.21	9.26

[1] No 9 ft. water table depth plots were sampled in 1975

[2] 1 inch = 2.54 cm.

Table 6 shows the plot irrigation schedule for 1975. The cold wet spring slightly reduced the need for irrigation.

Actual Attained Leaching Fractions

The water balance for the barrel lysimeters in the low leaching treatment plots is given in Table 7 and Table 8. A zero leaching fraction was attained for only one of the lysimeters in 1974. Tables 9 and 10 give the average adjusted leaching fractions attained for the plot-sized study area and for the sampling point in the plots for the treatments shown. The values in Tables 7, 8, 9, and 10 were obtained by using the amount of water received by the sampling point, the amount received by the study area, and the amount received by the lysimeter, for the respective calculations. The amount received by the lysimeter was determined for each plot by comparing the average of the catch in the can just north and the can just south of the

TABLE 7. 1974 SEASONAL WATER BALANCE FOR THE BARREL LYSIMETERS

Plot	5A1	5S1	7A1	7S1	9A1	9S1
Depth Applied (in.)[1/]	29.42	29.35	29.42	29.33	29.42	29.25
Drainage (in.)[1/]	.30	.28	3.10	1.35	1.95	3.23
Change in Storage (in.)[1/]	-.45	.60	0	0	2.40	0
Net* Leaching (in.)[1/]	[-.15]	.88	3.10	1.35	4.35	3.23
ET (in.)[1/]	29.57	28.47	26.32	27.98	25.07	26.02

Average Plot ET = 27.24 in.[1/]

---

*Minus indicates under irrigation.

[1/] 1 inch = 2.54 cm

lysimeter location in the sample plot to the average can-catch for the plot-sized study area of the whole sample plot. The amount of water received at the sampling location is determined for each plot by comparing the average of the can just east and the can just west of the sampling area of the sample plot to the average can-catch for the plot-sized study area.

The average leaching fractions attained for the treatments shown in Table 9 were very near to the desired leaching fractions in 1974. The actual leaching fractions for the study areas were slightly lower, while those for the sampling points were slightly higher than the target values. The 1975 values in Table 10 were more variable.

Depths to Water Table

Tables 11 and 12 show the average actual depths to water table throughout the season for all the 5 ft (1.5 m) plots, 7 ft (2.1 m) plots and 9 ft (2.7 m) plots measured.

TABLE 8. 1975 SEASONAL WATER BALANCE FOR BARREL LYSIMETERS

Plot	5A1	5S1	7A1	7S1
Depth Applied (in. Irrig. & Rain)[1/]	10.69	9.66	10.78	9.77
Drainage (in.)[1/]	0	0	0	0
Change in Storage (in.)[1/]	--	2.10	-2.28	1.80
Net Leaching (in.)* 1/	--	2.10	[-2.28]	1.80
ET (in.)[1/]	**	7.56	13.06	7.97

Average Plot ET = 9.53 inches[1/]

*Minus indicates under irrigation
** access tube damaged
[1/] 1 inch = 2.54 cm.

The depths shown in the 9 ft (2.7 m) depth column in Table 11 are not the true average. The piezometers in plots 9S2, 9A3, 9N3 and 9S3 could not be driven to the depth of the water table due to rocky conditions. The values shown for these areas were the end depths of the piezometers; the actual water table was deeper. The seasonal averages, high and low values, for each general water table depth are also given in Tables 11 and 12. It may be noted that the average water table depths were somewhat deeper than design called for in both years. The Ashley Valley had a short water year in 1974. Consequently, the irrigation water applied in the whole basin was somewhat lower than normal which in turn reduced the contribution to the ground water and resulted in a lower than normal water table. The water tables were higher in 1975 but were still not up to the design level.

TABLE 9. AVERAGE STUDY AREA AND SAMPLING POINT LEACHING FRACTIONS FOR EACH TREATMENT, 1974

	Treatment								
	A1	N1	S1	A2	N2	S2	A3	N3	S3
	Study Area								
Depth Applied (in.)1/	27.11	27.09	27.09	27.93	29.42	30.48	30.12	36.14	41.10
ET (in.)1/	27.24	27.24	27.24	27.24	27.24	27.24	27.24	27.24	27.24
Leaching* (in.)1/	[-.13]	[-.15]	[.15]	.69	2.18	3.24	2.88	8.90	13.86
Leaching* Fraction	[-.005]	[0.006]	[.025]	.074	.074	.106	.096	.246	.337
	Sampling Area								
Depth Applied (in.)1/	27.35	27.33	27.33	28.17	29.68	30.74	30.38	36.45	41.46
ET (in.)1/	27.24	27.24	27.24	27.24	27.24	27.24	27.24	27.24	27.24
Leaching (in.)1/	.11	.09	.09	.93	2.44	3.50	3.14	9.21	14.22
Leaching Fraction	.004	.003	.003	.030	.082	.114	.103	.253	.343

*Minus indicates under irrigation

1/ 1 inch = 2.54 cm

TABLE 10. AVERAGE STUDY AREA[1] LEACHING FRACTION FOR EACH TREATMENT, 1975

	Treatment								
	A1	N1	S1	A2	N2	S2	A3	N3	S3
Depth Applied (in.)[2]	9.80	10.57	8.78	10.09	10.75	8.94	10.21	11.10	9.18
ET (in.)[2]	9.53	9.53	9.53	9.53	9.53	9.53	9.53	9.53	9.53
Leaching (in.)[2]	.27	1.04	- .75**	.56	1.22	-.59	.68	1.57	-.35
Leaching Fraction	0.028	0.109	-0.079	0.059	0.128	-0.062	0.071	0.165	-0.037

**Minus indicates under irrigation

[1] The sampling area classification was not used in 1975.

[2] 1 inch = 2.54 cm

TABLE LL. AVERAGE DEPTHS TO WATER TABLE BY DATE FOR EACH WATER TABLE TREATMENT, 1974

	Minimum Desired Water Table Depth		
	5 ft (1.5 m)	7 ft (2.1 m)	9 ft (2.7 m)
Date	Depth to Water Table (ft)[1]		
5/16	7.01	8.84	11.21
6/05	6.47	8.46	11.06
6/06	6.43	8.44	10.94
6/07	6.39	8.39	10.88
6/10	6.36	8.35	10.73
6/12	6.50	8.37	10.78
6/14	6.59	8.47	10.80
6/17	6.66	8.52	10.81
6/19	6.58	8.56	10.86
6/21	6.59	8.56	10.90
6/24	6.81	8.67	10.96
6/26	5.99	8.03	10.99
6/27	6.47	8.48	11.06
6/28	6.72	8.63	11.05
7/03	7.33	9.00	11.17
7/06	7.04	8.81	11.16
7/08	6.94	8.72	11.14
7/10	7.30	8.59	11.16
7/16	7.53	9.08	10.97
7/18	7.37	8.99	10.83
7/22	7.07	8.82	10.73
7/26	7.18	8.88	10.69
7/30	7.37	8.87	10.65
8/01	7.40	8.99	10.60
8/05	7.37	9.01	10.63
8/07	7.52	9.12	10.72
8/09	7.50	9.09	10.77
8/12	7.71	9.20	10.79
8/14	7.71	9.22	10.88
8/20	7.87	9.33	11.02
8/23	7.86	9.29	11.13
8/27	7.89	9.27	11.03
8/28	7.88	9.30	10.96
8/30	7.52	9.08	10.93
9/04	7.72	9.26	11.11
9/06	7.90	9.36	11.30
9/13	8.01	9.41	11.40
Average	7.15	8.85	10.94
Minimum	5.99	8.03,	10.60
Maximum	8.01	9.41	11.40

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[1] 1 foot = 0.305 m

TABLE 12. AVERAGE DEPTHS TO WATER TABLE FOR EACH WATER TABLE TREATMENT, 1975

	Minimum Desired Water Table Depth	
	5 ft[1]	7 ft[1]
Date	Depth to Water Table (ft)[1]	
7-18	5.64	8.01
7-21	4.67	5.98
7-22	5.22	7.68
7-28	6.67	8.61
8-4	6.43	8.48
8-9	6.70	8.56
8-18	6.72	8.61
Average	6.01	7.99
Minimum Average	4.67	5.98
Maximum Average	6.72	8.61

[1] 1 foot = 0.305 m

Vertical Ground Water Movement

Tables 13, 14, and 15 summarize the matric potentials and hydraulic gradients by leaching treatment, water quality treatment and depth to water table at the 4.5 ft (1.4 m) depth in 1974. A negative value for hydraulic gradient indicates upward flow. No attempt was made to quantitatively correlate these readings to the various treatments. They only indicate direction of flow and relative matric potential deep in the soil profile.

The experiment was designed to manage irrigation to maintain downward flow since continuous downward flow makes determination of water and salt balances easier. The goal was accomplished generally for all treatments. The lower water table depth for the 1974 season probably helped maintain the downward gradient. Higher water table conditions may have necessitated a shorter irrigation interval to prevent some upward movement of water from the shallower water tables into the root zone between irrigations.

Salinity Monitoring

The measured quality of the irrigation waters applied in both years is shown in Tables 16 and 17. There was a considerable fluctuation in the quality of water from the South Tributary. This was due to fluctuations in flow.

TABLE 13. MATRIC POTENTIAL AND VERTICAL HYDRAULIC GRADIENT AVERAGES FOR THREE LEACHING FRACTION TREATMENTS IN 1974

Date	Low Leaching		Middle Leaching		High Leaching	
	Matric Potential Mb	Gradient	Matric Potential Mb	Gradient	Matric Potential Mb	Gradient
6/10	106.1	0.79	83.1	0.82	66.0	0.58
6/15	131.4	0.60	95.2	0.44	83.3	0.88
6/20	131.6	0.27	110.6	0.43	100.6	0.63
6/25	119.9	-0.03	107.2	0.84	79.4	1.09
6/30	136.3	-0.13	119.2	0.94	90.2	0.54
7/05	131.4	1.26	123.6	0.99	97.6	0.76
7/10	118.1	1.13	108.0	1.55	88.6	0.72
7/15	165.8	1.44	122.0	1.70	110.2	0.88
7/20	125.6	1.78	84.5	1.33	74.9	0.60
7/25	129.7	0.62	112.1	0.78	100.4	0.45
7/30	125.7	0.51	124.3	0.42	113.0	0.34
8/04	94.3	1.12	94.7	0.51	69.4	0.79
8/09	110.3	0.86	113.0	0.93	89.8	0.40
8/14	106.6	1.51	99.9	1.33	72.6	0.47
8/19	122.2	0.87	117.7	0.83	96.4	0.32
8/24	114.3	1.06	93.7	1.02	98.2	1.27
8/29	94.2	1.49	97.3	1.24	80.1	0.83
9/03	117.8	1.04	126.2	1.03	102.5	0.53
9/08	141.5	0.92	162.5	1.23	128.3	0.63

TABLE 14. MATRIC POTENTIAL AND VERTICAL HYDRAULIC AND GRADIENT AVERAGES FOR THREE IRRIGATION WATER QUALITY TREATMENTS IN 1974

Date	High Water Quality Matric Potential Mb	High Water Quality Gradient	Middle Water Quality Matric Potential Mb	Middle Water Quality Gradient	Low Water Quality Matric Potential Mb	Low Water Quality Gradient
6/10	99.6	0.45	81.8	1.23	73.8	0.51
6/15	120.6	0.27	96.3	1.20	93.0	0.45
6/20	120.2	0.14	112.8	0.84	109.8	0.35
6/25	118.8	0.11	86.5	0.87	101.2	0.92
6/30	126.6	0.09	114.9	0.66	104.1	0.59
7/05	158.0	1.47	73.1	1.35	121.6	0.18
7/10	111.1	1.43	105.2	0.62	98.4	1.34
7/15	133.2	2.70	136.5	0.60	128.3	0.73
7/20	111.1	2.03	92.3	0.99	81.6	0.69
7/25	119.1	1.10	115.5	0.52	107.8	0.24
7/30	120.7	0.54	127.2	0.59	115.1	0.15
8/04	91.3	0.62	74.9	1.29	92.2	0.52
8/09	106.0	0.95	104.2	0.75	102.9	0.49
8/14	100.7	1.35	82.6	1.11	95.8	0.84
8/19	111.5	0.87	108.0	0.67	116.9	0.48
8/24	103.4	2.36	88.2	0.69	114.6	0.29
8/29	96.5	1.75	92.6	0.93	82.4	0.88
9/03	114.7	1.14	114.7	1.01	117.1	0.44
9/08	146.0	0.90	141.9	0.84	144.4	1.04

TABLE 15. MATRIC POTENTIAL AND VERTICAL HYDRAULIC GRADIENT AVERAGES FOR THREE WATER TABLE DEPTH TREATMENTS IN 1974

Date	5 ft [1] Water Table		7 ft [1] Water Table		9 ft [1] Water Table	
	Matric Potential Mb	Gradient	Matric Potential Mb	Gradient	Matric Potential Mb	Gradient
6/10	78.7	0.38	75.7	1.24	100.7	0.56
6/15	98.8	0.16	91.5	1.27	119.6	0.46
6/20	96.8	-0.37	104.0	0.94	142.0	0.75
6/25	89.7	0.08	86.1	1.23	130.8	0.59
6/30	101.9	0.25	108.3	0.75	135.4	0.34
7/05	95.9	1.41	111.7	1.05	145.1	0.56
7/10	87.2	1.47	102.2	11.5	125.3	0.77
7/15	125.9	1.66	120.7	1.47	151.4	0.90
7/20	86.8	1.86	102.4	0.85	95.9	1.00
7/25	97.0	0.56	113.2	0.61	132.1	0.69
7/30	102.4	0.36	116.5	0.63	144.1	0.28
8/04	64.8	1.07	85.8	1.08	107.8	0.27
8/09	87.2	0.64	92.8	0.98	133.1	0.57
8/14	73.2	1.36	83.1	1.14	122.8	0.80
8/19	96.1	0.63	94.5	0.89	145.7	0.50
8/24	80.6	0.70	81.7	1.63	143.9	1.01
8/29	86.1	0.82	88.2	1.53	97.3	1.21
9/03	106.7	0.62	109.5	1.14	130.3	0.84
9/08	132.8	0.89	140.9	1.27	158.6	0.63

[1] 1 foot = 0.305 m

TABLE 16. IRRIGATION WATER QUALITIES FOR EACH IRRIGATION FOR ASHLEY CREEK, NAPLES DRAIN AND SOUTH TRIBUTARY, 1974

	Electrical Conductivity, mmhos/cm		
Irrigation Number	Ashley Creek	Naples Drain	South Tributary
1	1.05	2.45	1.29
2	1.05	2.82	3.15
3	1.08	2.13	2.26*
4	1.02	1.91	4.38
5	.63	1.70	1.81
6	1.03	1.88	4.01
7	1.01	2.62	2.72
Average	.98	2.22	2.80

*Storage reservoir in operation

TABLE 17. IRRIGATION WATER QUALITIES IN 1975

	EC, (mmhos/cm)		
Irrigation Number	Ashley Creek	Naples Drain	South Tributary
1	.660*	.660*	.660*
2	.660	1.718	1.592
3	.708	1.472	1.483
Average	.676	1.283	1.245

*First irrigation used Ashley Creek water for all irrigations, EC assumed to be .660

When farmers upstream were irrigating, surface runoff entered the channel and improved the water quality. The construction of the storage reservoir on this stream allowed collection and use of the very low flows which were of lower quality. This was particularly true in 1975. The South Tributary of the Naples Drain had a lower average salinity than the Naples Drain. The storage helped average the quality but some fluctuation still occurred. Fluctuation in the quality of the Naples Drain was due to the same effect. The normal stream flow is of higher quality than the surface runoff water. When runoff water entered the stream, the quality was lowered.

Even though there were fluctuations in the quality of all three irrigation water supplies, the average for the season was quite close to the expected values in 1974, with each being of a slightly lower quality than anticipated.

Before examining the actual seasonal change in average profile salinity it is helpful to reexamine Table 1, showing the design salinity of the drainage water for each leaching fraction, and to look at the changes in soil profile salinity expected. The values in Table 1 are the design figures. By using the actual attained leaching fractions for the sample areas given in Tables 9 and 10 and the average irrigation water quality from Tables 16 and 17, and by using Equation [3], the values for the theoretical expected EC_{dw} in Tables 18 and 19 were obtained.

Assuming a straight line salinity profile varying from the conductivity of the irrigation water at the top to the design EC_{dw} at the bottom, the expected average profile salinity for each of the above conditions can be found. These values are shown in Table 20 and all assume no precipitation or dissolution of salts. It seems obvious that no plant could continue to extract water from a soil with the average profile salinity indicated in row 1 of Table 20. The actual salinity values measured in the field were much lower.

Since all the salinity values in Table 20 are theoretical equilibrium values, it is not expected that they would be reached in one season. To predict the expected increase in salinity for 1974, a salt balance for each treatment condition was made. The expected change in soil water salinity is given by

$$\Delta EC_{sw} = \frac{D_{iw} \times EC_{iw} - D_{dw} \times EC_{dw}}{D_r \times \theta_{fc}} \qquad [14]$$

where

ΔEC_{sw} = change in electrical conductivity of the soil water
D_{iw} = depth of irrigation water
EC_{iw} = electrical conductivity of irrigation water
D_{dw} = depth of drainage water
EC_{dw} = electrical conductivity of drainage water
D_r = depth of root zone
θ_{fc} = moisture content by volume at field capacity (0.30 for Vernal soil).

TABLE 18. THEORETICAL EC$_{dw}$ IN MMHOS/CM FOR EQUILIBRIUM CONDITIONS USING 1974 WATER QUALITY AND LEACHING FRACTIONS

Irrigation Water Quality EC, mmho/cm					
Ashley .98		Naples 2.22		South Tributary 2.80	
L.F.	Expected EC$_{dw}$ mmho/cm	L.F.	Expected EC$_{dw}$ mmho/cm	L.F.	Expected EC$_{dw}$ mmho/cm
.004	245.0	.003	740.0	.003	933.3
.030	32.7	.082	27.1	.114	24.6
.103	9.5	.253	11.1	.343	8.2

TABLE 19. THEORETICAL EXPECTED EC$_{dw}$ IN MMHOS/CM FOR EQUILIBRIUM CONDITIONS USING ACTUAL 1975 QUALITIES AND LEACHING FRACTIONS

Irrigation Water Quality EC, mmho/cm					
Ashley 0.676		Naples 1.283		South Tributary 1.245	
L.F.	Expected EC$_{dw}$ mmho/cm	L.F.	Expected EC$_{dw}$ mmho/cm	L.F.	Expected EC$_{dw}$ mmho/cm
.028	24.1	.109	11.7	-.079[1]	
.059	11.5	.128	10.0	-.062	
.071	9.5	.165	7.8	-.037	

[1] Negative leaching fraction, i.e.,

TABLE 20. THEORETICAL AVERAGE PROFILE SALINITY FOR EQUILIBRIUM CONDITIONS USING 1974 WATER QUALITIES AND LEACHING FRACTIONS

Leaching Fraction	Irrigation Water Quality Treatment High	 Medium	 Low
	Average Profile Salinity, mmho/cm		
Low	123.0	371.0	468.0
Medium	15.3	14.7	13.7
High	5.2	5.5	5.5

The quality of the drainage water was taken to be the quality of the 42-inch (1.06 m) depth soil solution extract and the root zone was assumed to be 42 inches (1.06 m) deep. This procedure assumes all salt in the profile is in solution. The results of these calculations appear in Table 21 for 1974 and in Table 22 for 1975.

Figure 10 gives the measured and expected average soil profile salinity for the 1974 season for the three water table depth treatments. The figure shows that the measured changes are much smaller than the expected changes. Figure 11 shows similar data for 1975. The expected salinity increased from the application of irrigation water and the measured salinity remained relatively constant through both seasons. An increase in measured salt concentration in the soil solution was found as the soil dried following the last irrigation. All other measurements were taken with the soil near field capacity. Figures 12, 13, 14, and 15 show similar results for the three irrigation water quality treatments and three leaching treatments, respectively. In some cases, the measured soil profile salinity actually decreased when an increase was expected. In no case did the expected and measured change in salinity agree. It must be remembered that in all cases the expected change in average profile salinity assumes no precipitation or dissolution of salts. The water table depth treatments showed no appreciable effect on soil profile salinity. In Figure 12 there is a slight separation in the curves of measured salinity with an improvement in soil profile salinity where high quality water was used. The low quality water treatment caused a slight increase in average profile salinity over the season but the effect was much less than expected. The leaching treatment averages shown in Figure 14 show a higher average salinity for the low leaching treatment but only a slight seasonal increase.

To see where the changes in salinity occurred, it is important to look at the individual treatment salinity profiles at intervals throughout the season. Figure 16 shows the average soil solution salinity profile at three

TABLE 21. EXPECTED CHANGE IN AVERAGE SOIL PROFILE SALINITY FOR THREE LEACHING FRACTIONS, THREE WATER QUALITIES AND THREE DEPTHS TO WATER TABLE FOR 1974

Leaching Fraction	Change in Salinity mmho/cm	Water Quality	Change in Salinity mmho/cm	Water Table Depth	Change in Salinity mmho/cm
Low	[1]+4.27	Low	+5.45	Low	+3.97
Medium	+4.00	Medium	+4.40	Medium	+3.92
High	+3.03	High	+1.81	High	+3.64

[1] + indicates the expected change in salinity.

TABLE 22. EXPECTED CHANGE IN AVERAGE SOIL PROFILE SALINITY FOR THREE LEACHING FRACTIONS, THREE WATER QUALITIES AND TWO DEPTHS TO WATER TABLE, 1975

Leaching Fraction	Change in Salinity mmho/cm	Water Quality	Change in Salinity mmho/cm	Water Table Depth	Change in Salinity mmho/cm
Low	+ .84	Low (S)	+ .89	1/	
Medium	+ .86	Medium (N)	+1.10	Medium (7) 2/	+ .84
High	+ .89	High (A)	+ .542	High (5) 2/	+ .83

1/ 9 foot (2.7 m) water table treatment not included in 1975

2/ 1 foot = 0.305 meters

+ indicates increased salinity

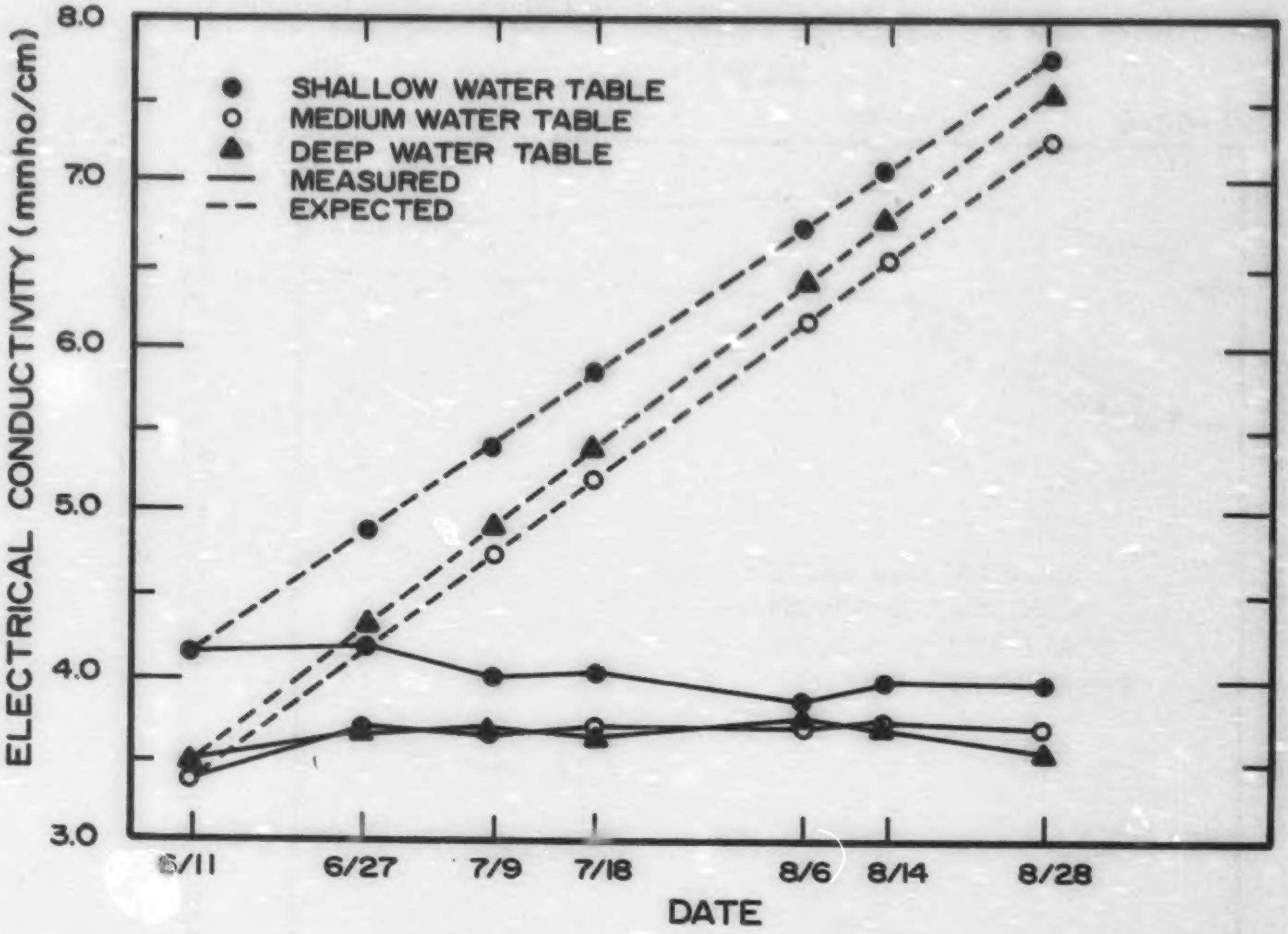


Figure 10. Measured and expected average soil water salinity for three water table depth treatments, 1974.

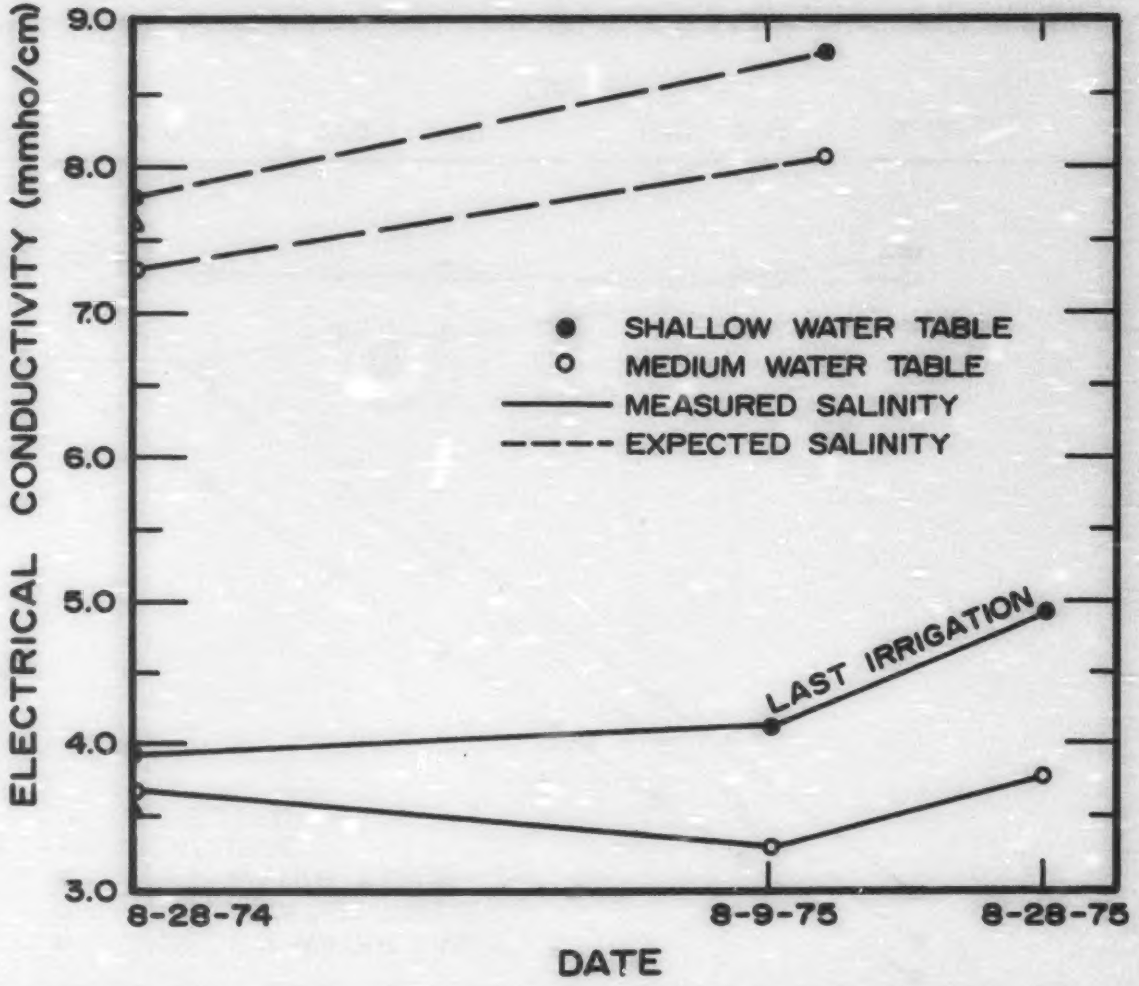


Figure 11. Measured and expected average soil water salinity with time for two water table depth treatments in 1975.

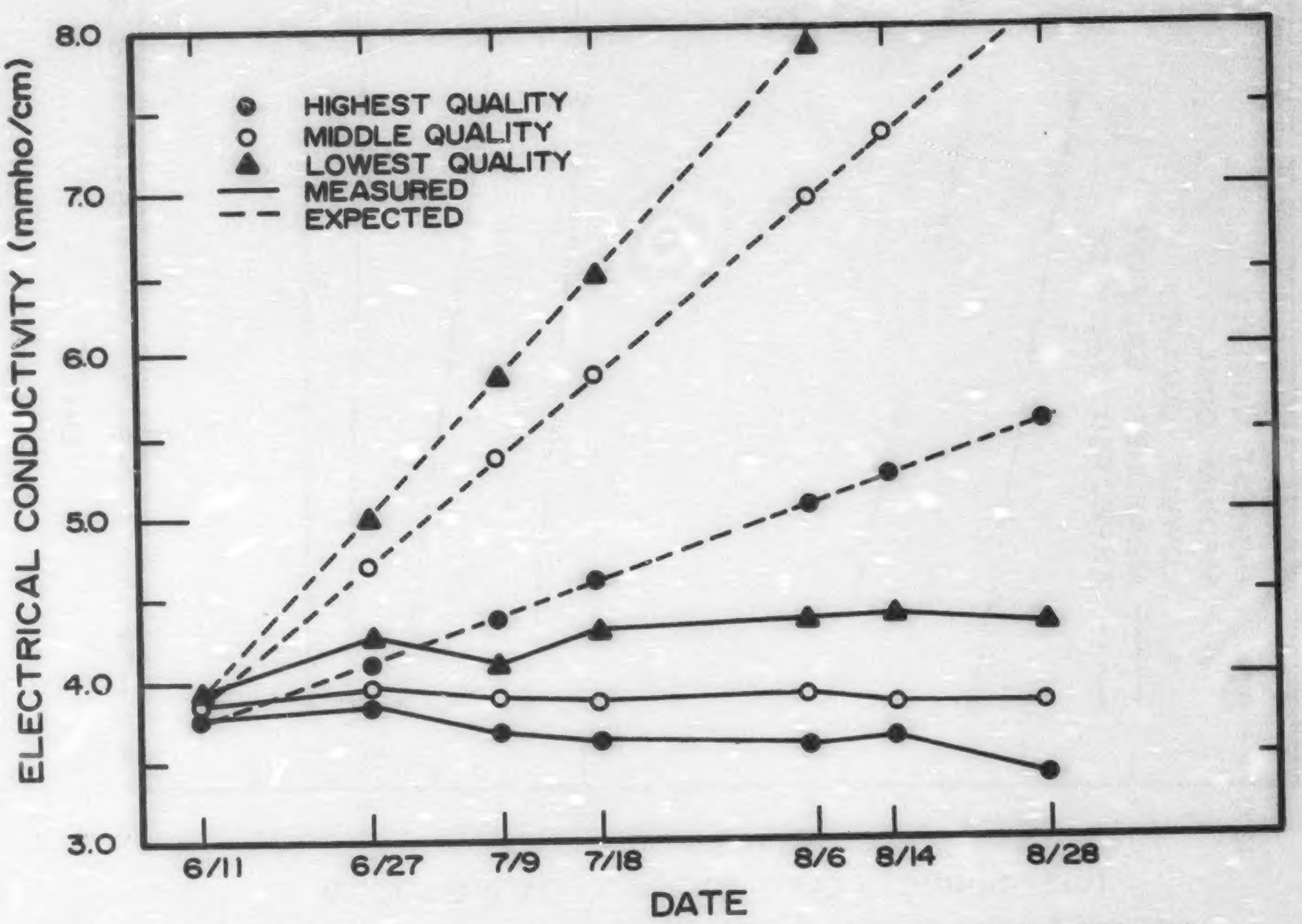


Figure 12. Measured and expected average soil water salinity for three irrigation water quality treatments.

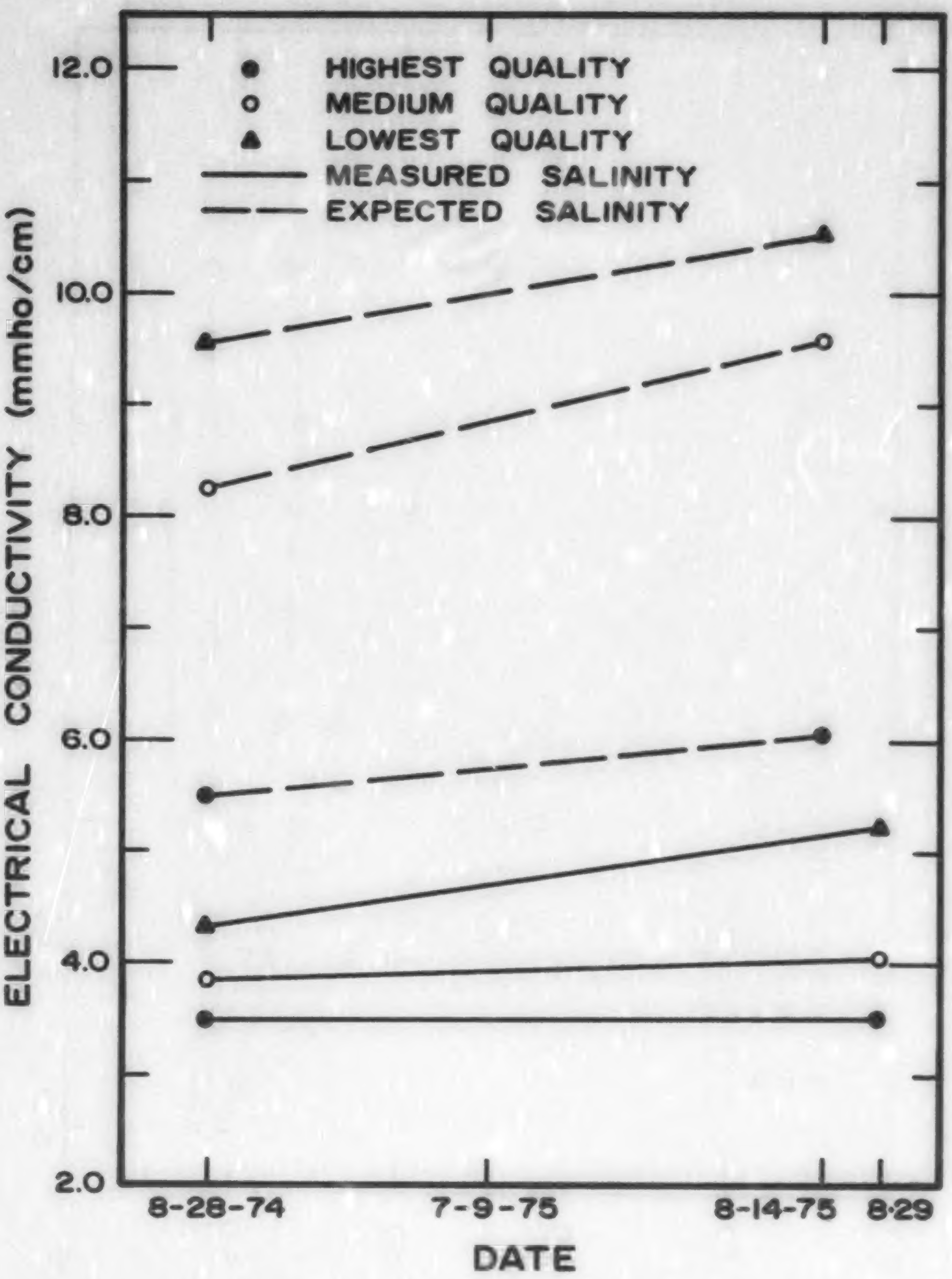


Figure 13. Measured and expected average soil water salinity with time for three irrigation water quality treatments.

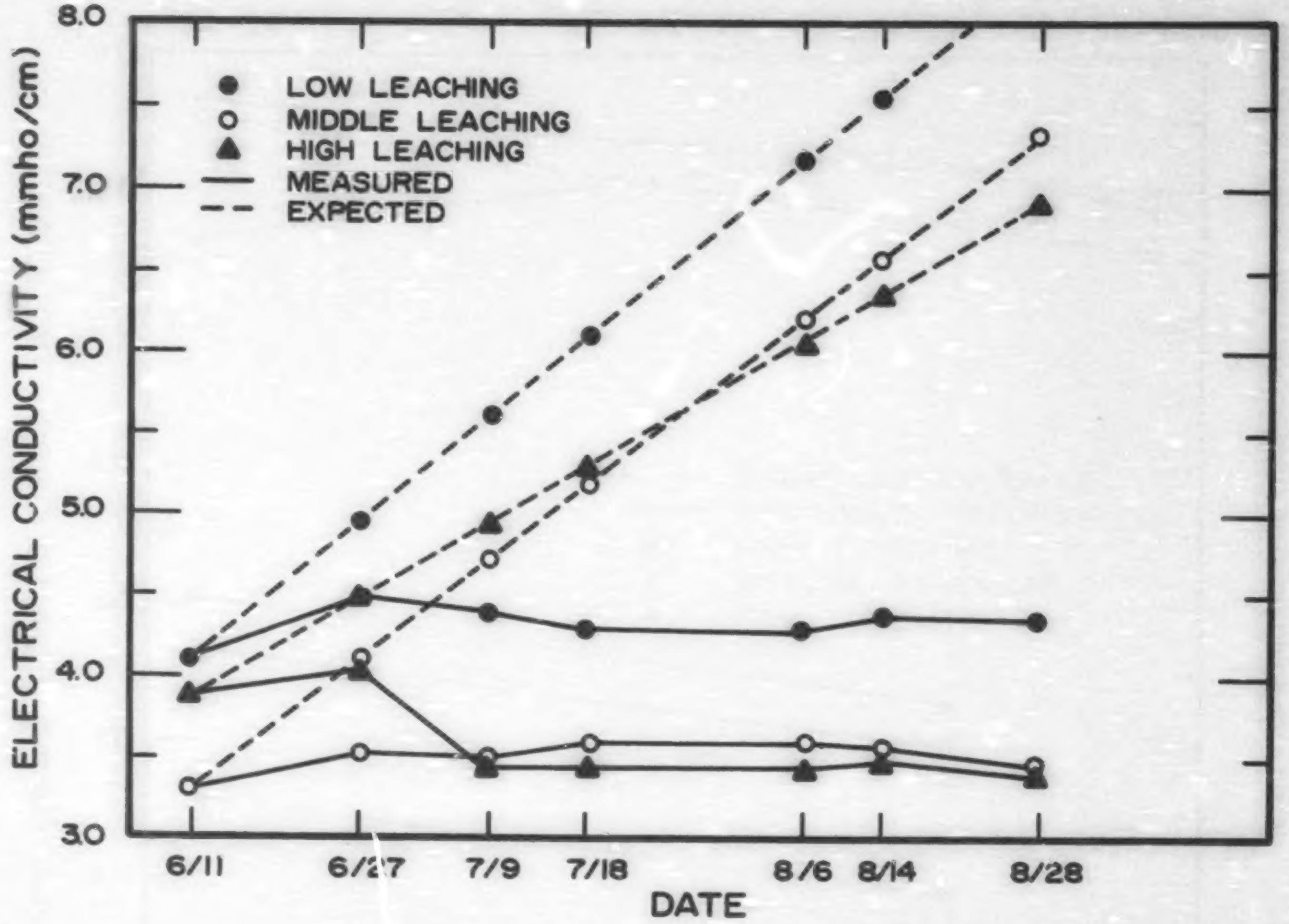


Figure 14. Measured and expected average soil water salinity for three leaching treatments, 1974.

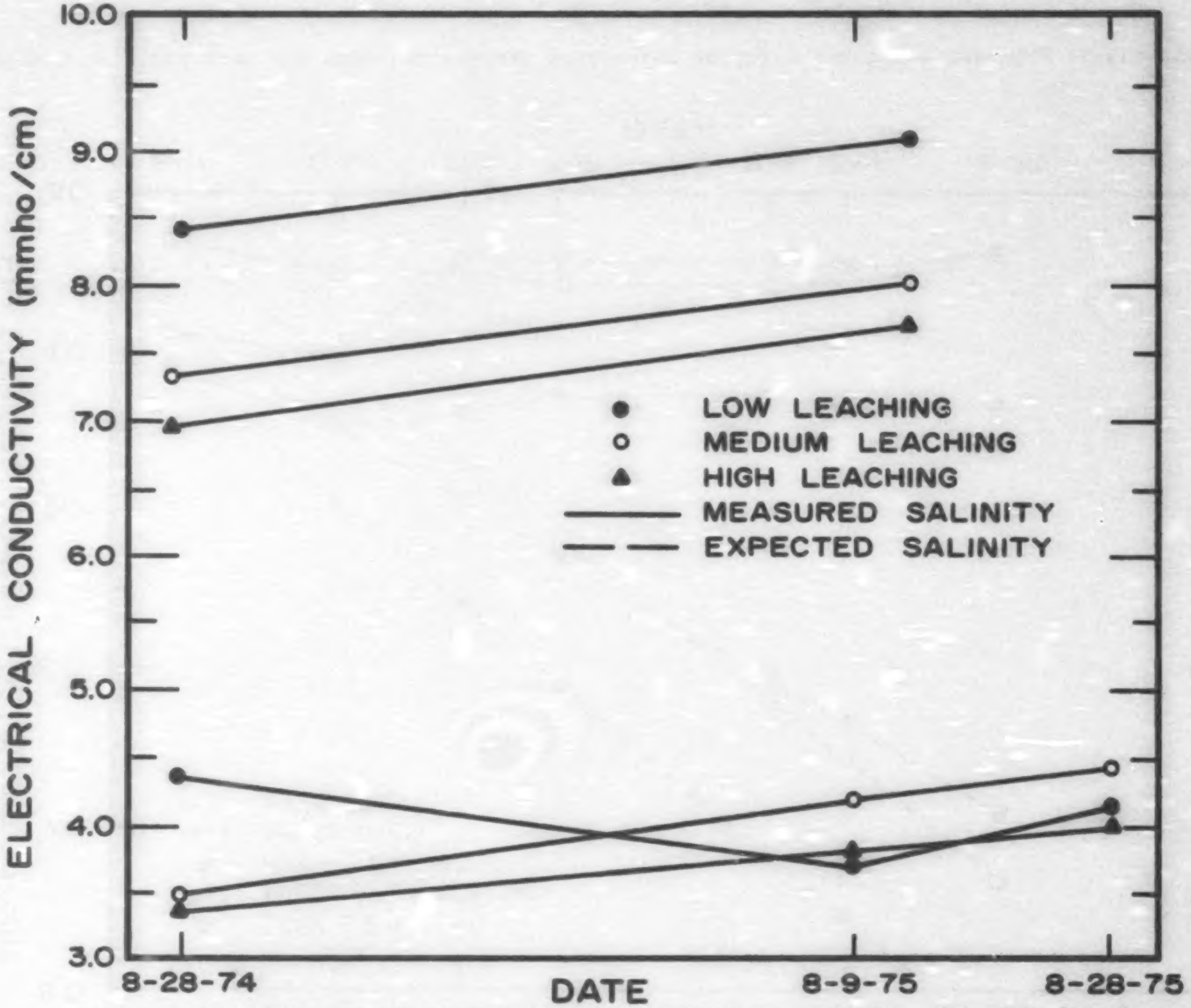


Figure 15. Measured and expected average soil water salinity with time for three leaching fractions.

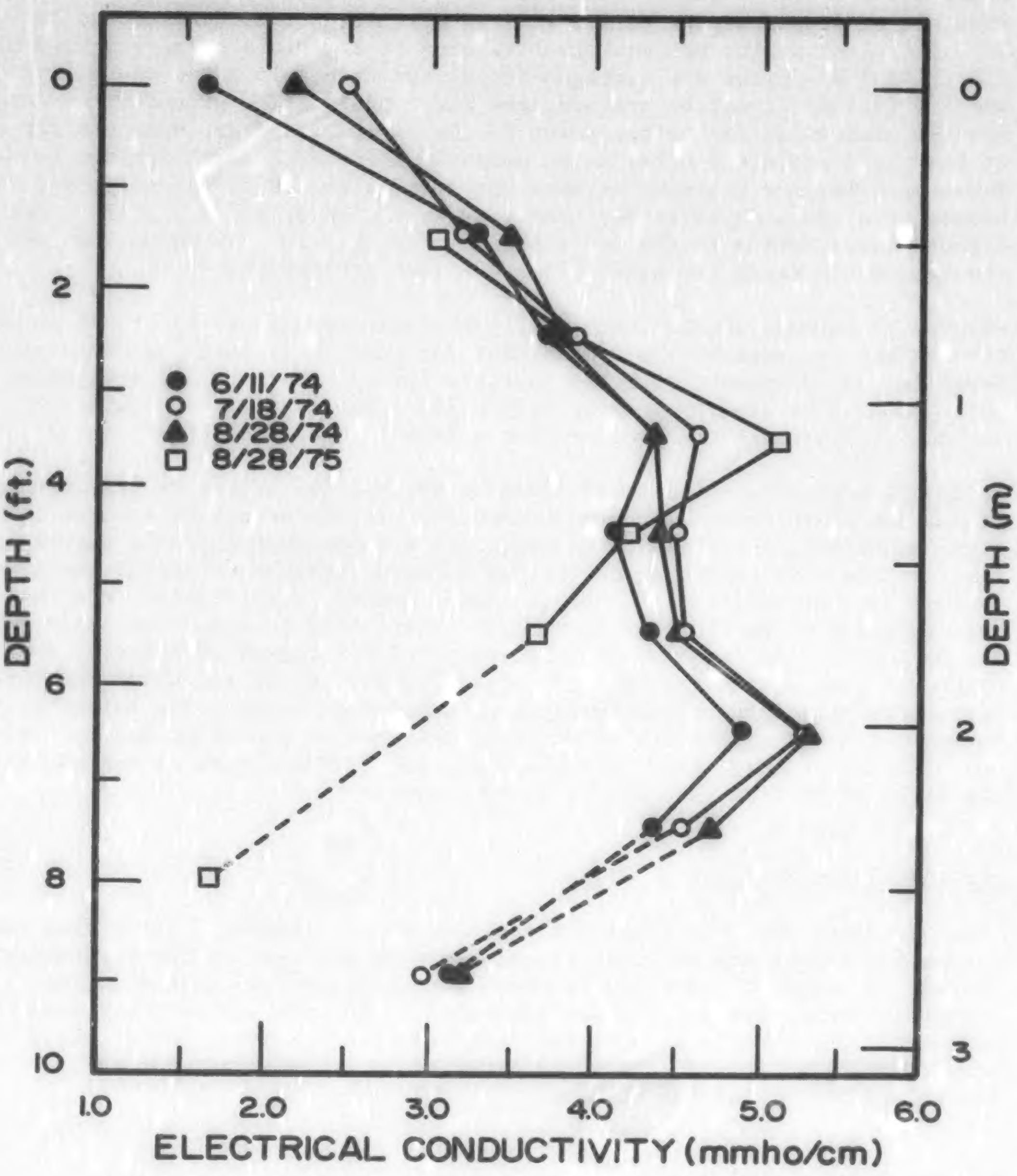


Figure 16. Average soil solution salinity profiles for low leaching plots on four dates.

times during the 1974 season and at the end of the 1975 season for the averaged low leaching treatments. The profiles are not true average profiles below 3.5 ft (1.1 m) because the shallower water table plots did not have samplers at deeper depths to 7.5 ft (2.3 m). The points down to and including 3.5 ft (1.1 m) depths are averages for nine or six plots. The 4.5 (1.4 m) and 5.5 ft (1.7 m) depths are averages for six or three plots and the 6.5 (2.0 m) and 7.5 (2.3 m) ft depths are averages for 3 plots. The ground water data are all plotted as the bottom point in the figures, and are averages for nine or six plots and are plotted at an average water table depth for the season. These profiles are included to show the average change in salinity over the season at a given depth rather than to show a true salinity profile. The higher concentration in the upper profile for 1975 is related to the fact that the sample was taken two weeks after the last irrigation.

Figures 17 through 24 show essentially the same results as Figure 16 for the other eight treatments. No significant increase in salinity is noted at any depth for any treatment with the possible exception of the low irrigation water quality treatment shown in Figure 19. Figure 19 shows a salt accumulation high in the profile, but a loss at deeper depths.

It is apparent from the results shown in Figures 10 through 24 that precipitation and dissolution of salts in the soil profile cannot be ignored in water management for salinity control. It appears that the salt saturation limit of the soil water varies, but at a given location or depth, any attempt to increase the salinity of the soil water causes precipitation, and the concentration of the soil water remains essentially constant, at least for the period of time involved in this study. The increase in salinity seen in Figure 19 came at the 1.5 (0.5 m) and 2.5 ft (0.8 m) levels where the more saline irrigation water was added to an unsaturated zone. The salinity, however, did not exceed the salinity of the soil at the lower depths. Adding saline or non-saline water to the profile had little effect on the equilibrium condition of salt in the profile in two seasons.

Individual Ion Analysis

Table 23 gives the individual ion analysis of one sample of water from each irrigation supply and one soil solution sample for each of the treatments listed. Examination of Table 23 shows that most of the cations in the irrigation water are calcium and magnesium. The majority of the anions are sulfates. The same is true of the soil solution extracts. Under these conditions, precipitation would be expected to be important due to the low solubility of calcium sulfate.

Diluted Extract Analysis

To further support the precipitation premise, soil samples for different depths from some of the plots were taken. 1:0.4, 1:1 and 1:5 extracts were prepared for each sample, and the electrical conductivity of the extract measured. If there were no dissolution of precipitated salts, the conductivity of the 1:1 extracts would be expected to be 5 times the conductivity of the 1:5 extracts.

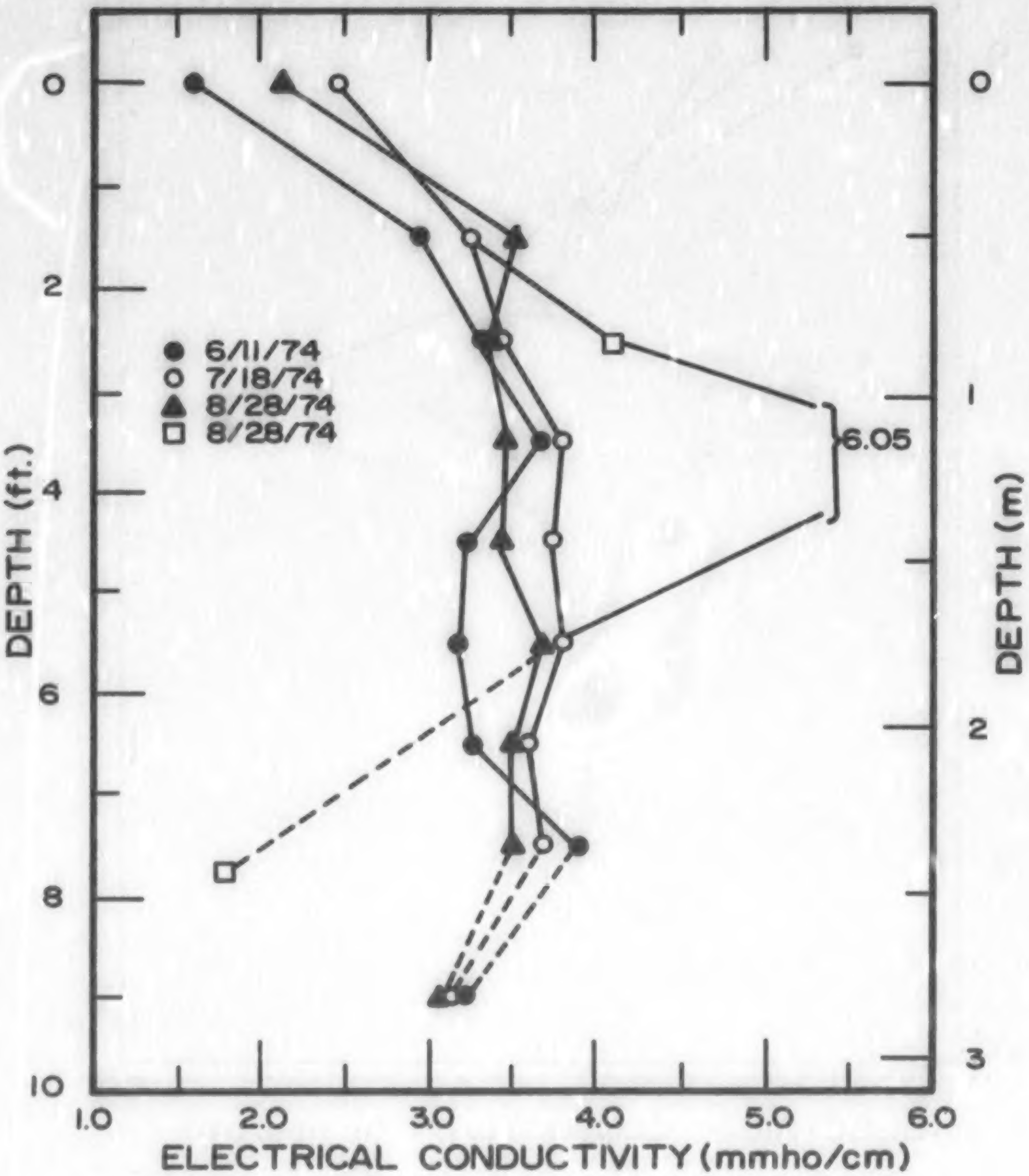


Figure 17. Average soil solution salinity profiles for middle leaching plots on four dates.

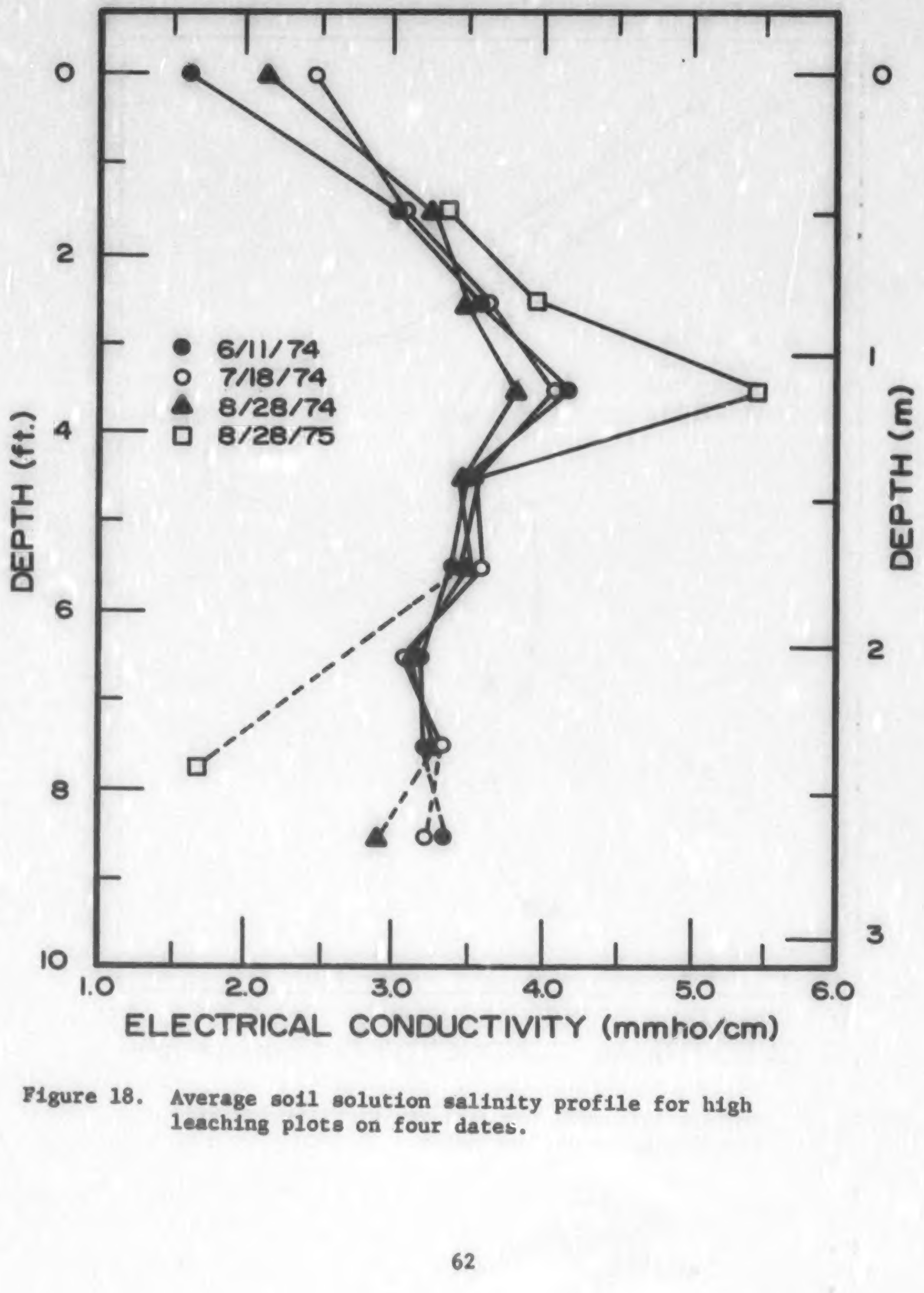


Figure 18. Average soil solution salinity profile for high leaching plots on four dates.

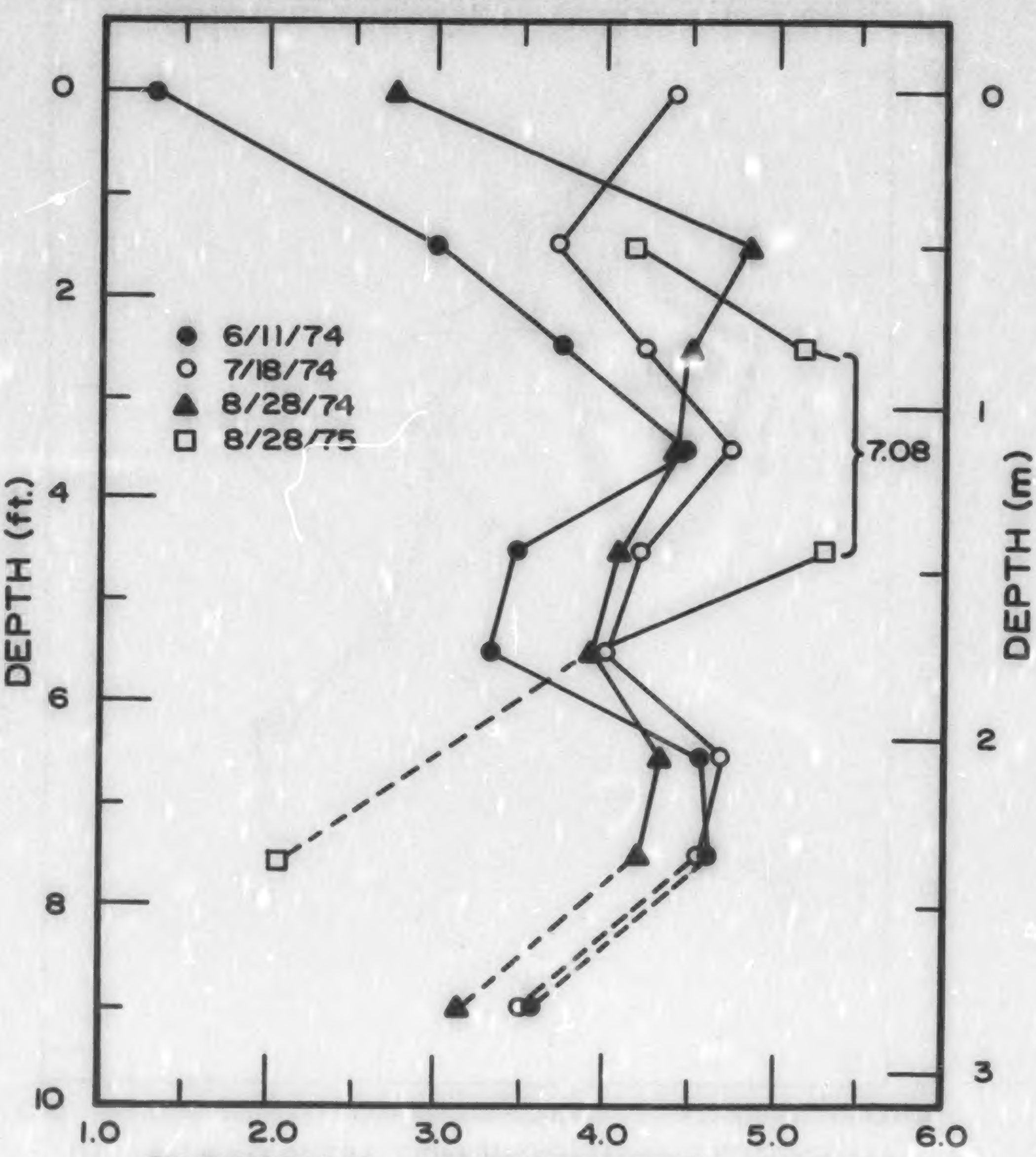


Figure 19. Average soil solution salinity profiles for low water quality plots on four dates.

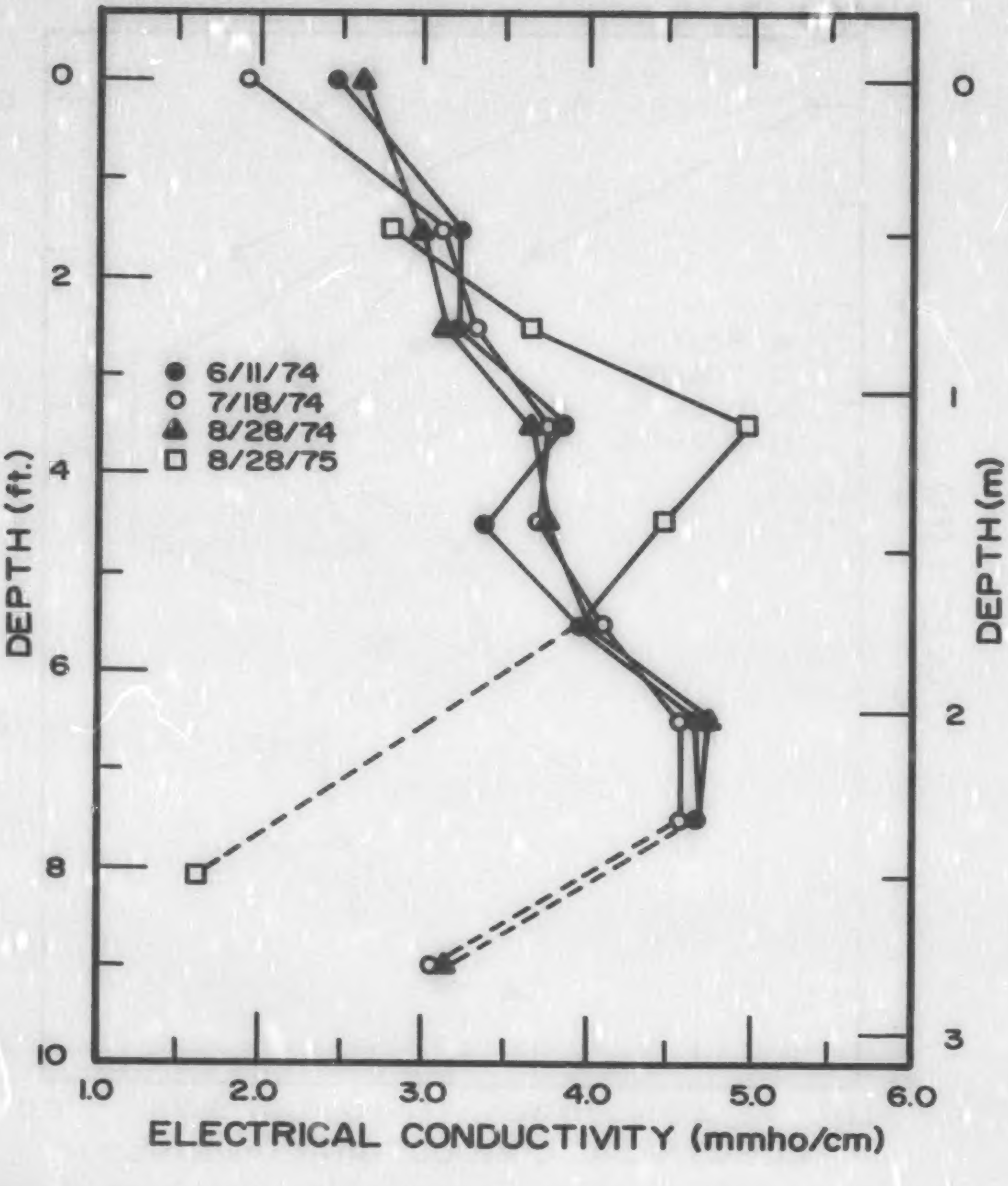


Figure 20. Average soil solution salinity profile for middle water quality plots on four dates.

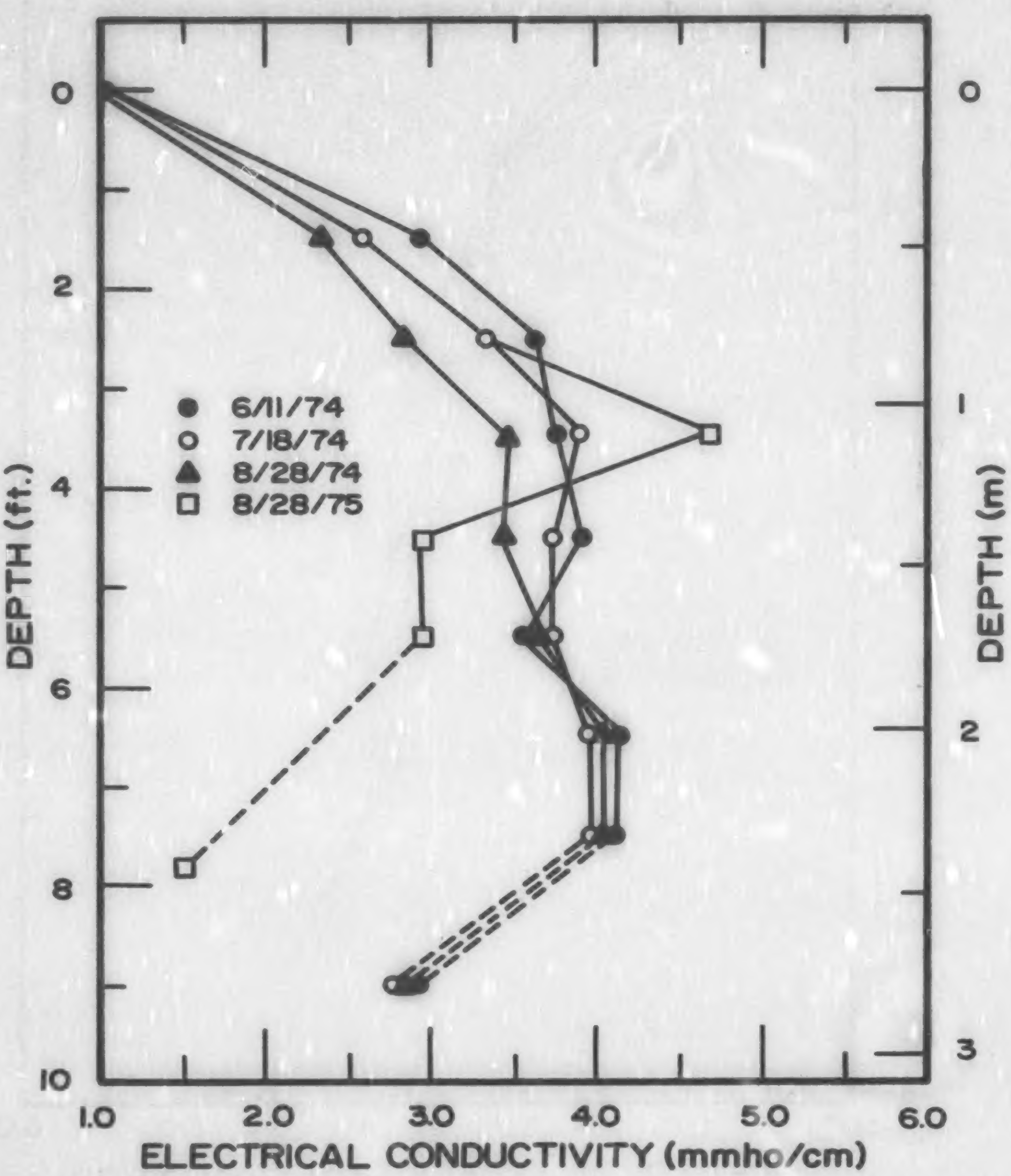


Figure 21. Average soil solution salinity profile for high water quality plots on four dates.

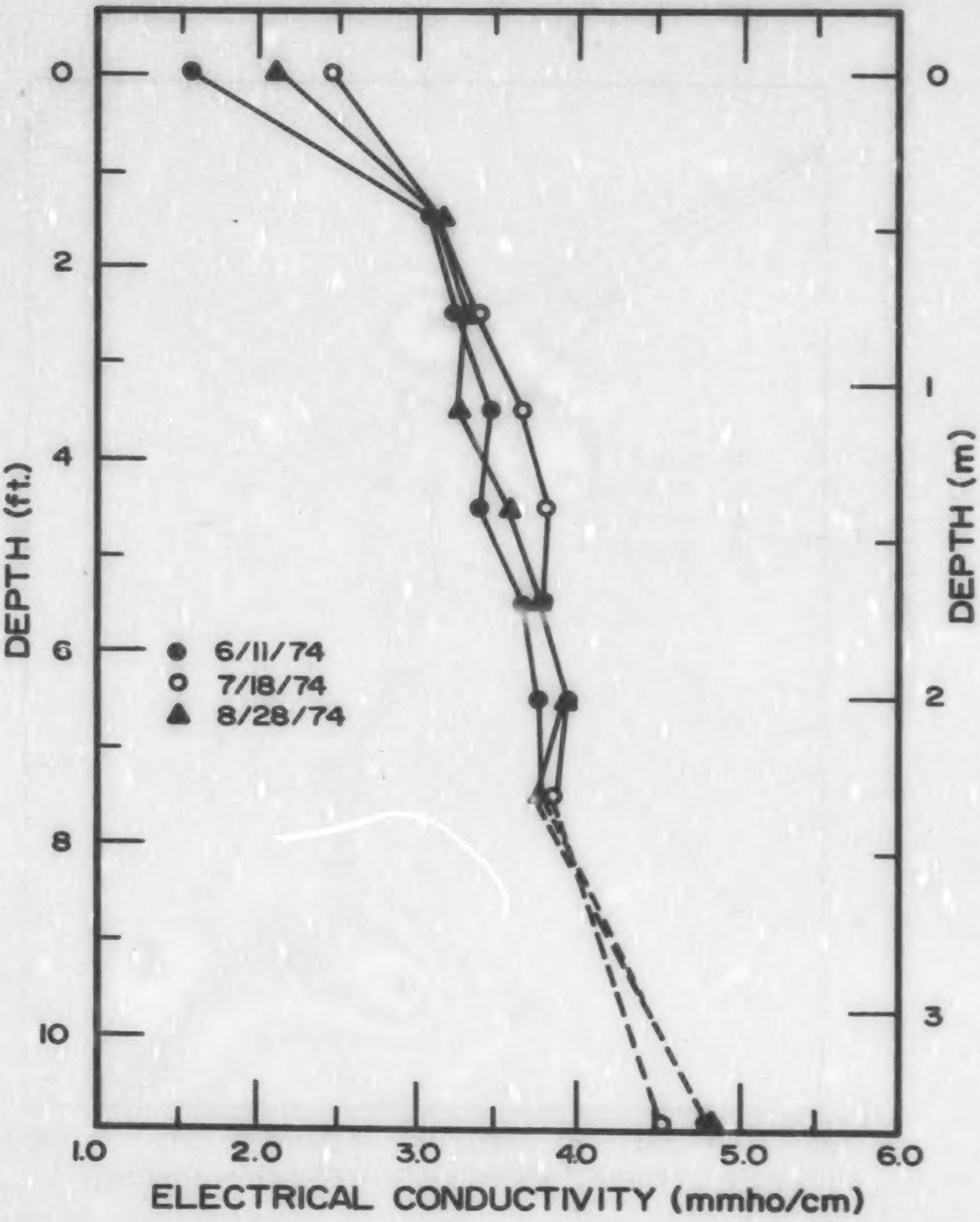


Figure 22. Average soil solution salinity profile for deep water table on three dates.

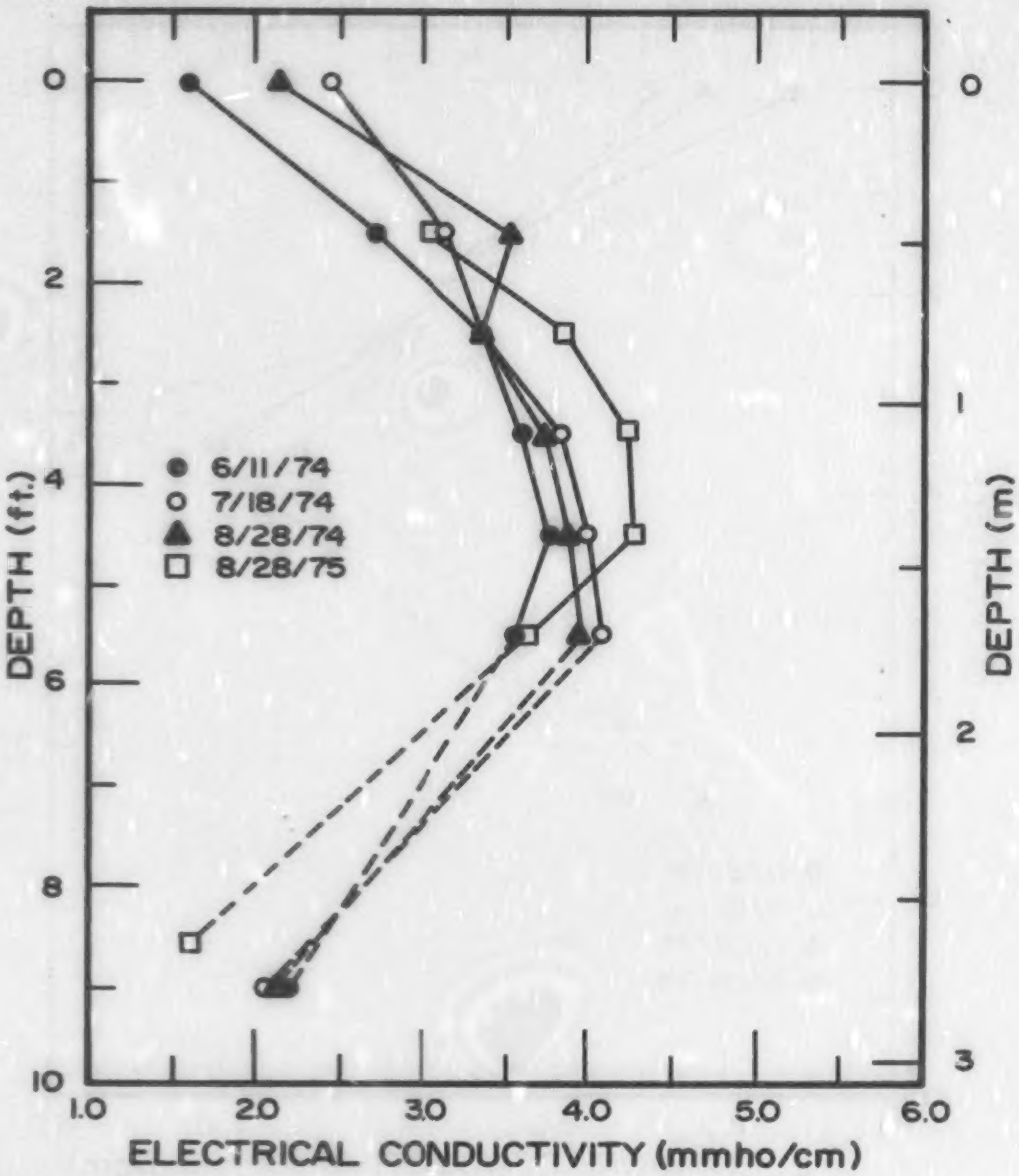


Figure 23. Average soil solution salinity profile for middle water table depth on four dates.

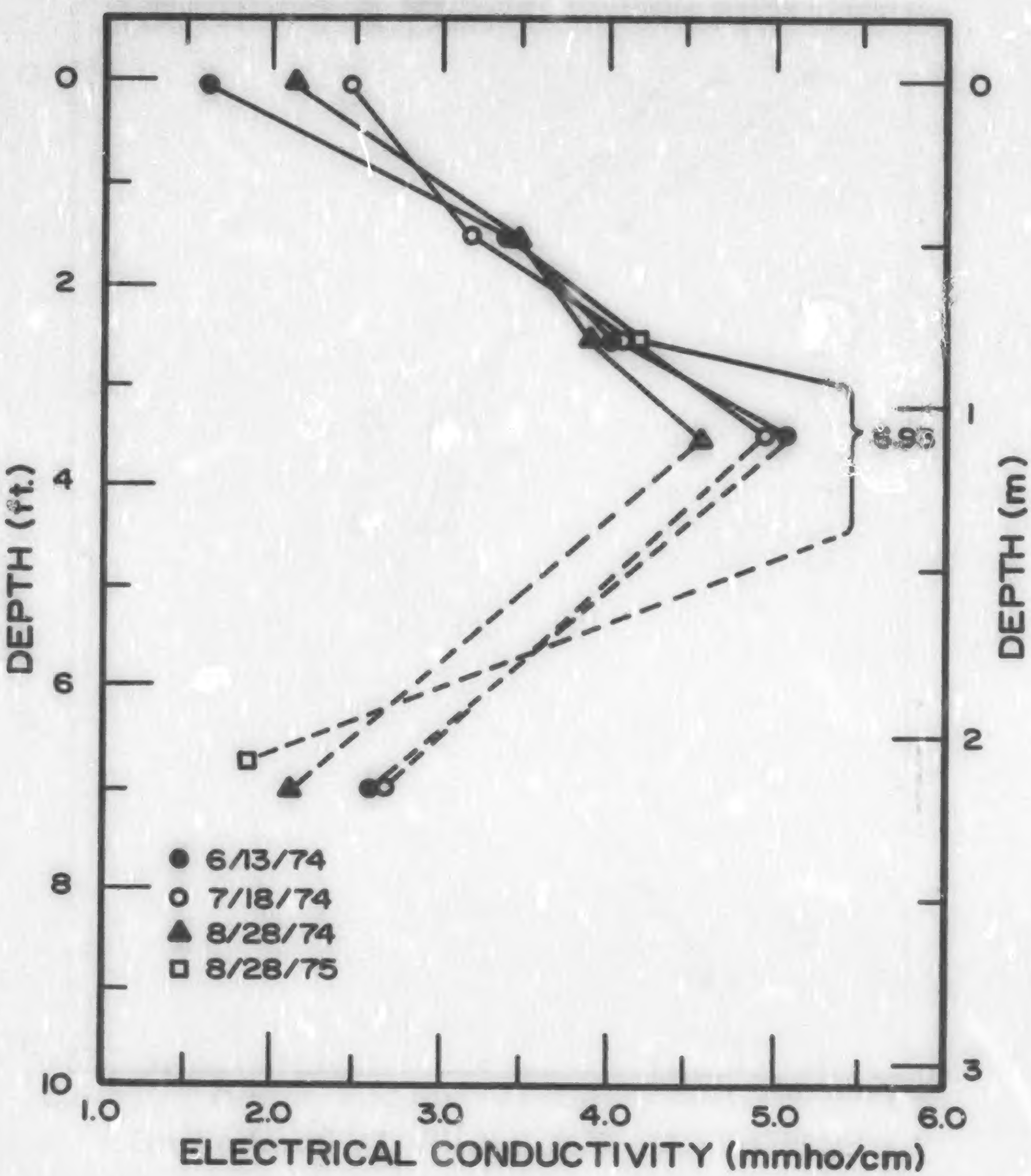


Figure 24. Average soil solution salinity profile for shallow water table on four dates.

TABLE 23. INDIVIDUAL ION ANALYSES OF SELECTED IRRIGATION WATER SAMPLES AND SOIL SOLUTION EXTRACTS

	Cations				Anions			
Treatment	Ca	Mg	Na	K	Cl	SO_4	CO_3	HCO_3
	Milliequivalents/Liter							
I.W.A.[1]	9.18	8.91	.87	.05	.30	15.00	.90	2.20
I.W.N.	12.03	13.08	4.74	.21	1.00	17.00	.60	9.20
I.W.S.	11.23	13.90	6.74	.16	1.00	26.90	.60	3.80
5A	14.97	36.77	2.44	.05	.10	49.90	1.00	2.40
7A	14.80	25.17	2.35	.25	.40	36.20	1.50	4.00
9A	13.27	36.05	7.74	.20	2.70	47.20	1.00	4.00
5N	14.82	28.30	2.39	.20	1.00	37.90	1.20	2.10
7N	14.02	32.90	4.13	.29	.80	46.20	1.10	2.60
9N	23.40	27.47	5.96	.17	1.80	42.80	1.10	7.40
5S	16.87	62.43	4.39	.26	.80	68.00	3.20	6.50
7S	16.67	43.19	5.22	.23	.70	54.10	1.60	7.00
9S	22.90	30.11	5.31	.14	1.50	45.70	1.60	5.40

[1] I.W. means irrigation water.

Table 24 gives the results of this experiment on the field soil samples. In the table, columns 2 and 5 would be the same if there were no dissolution of precipitated salts. In each case, however, even at the shallow depths, some precipitated salts are evidently present. The amount of precipitated salts generally increases with depth as would be expected. There are apparently three to six times as much salt precipitated in the soil as is in the soil solution at the saturation water content.

ET Prediction and Irrigation Scheduling

In order to evaluate the ET prediction section of the irrigation scheduling program for management purposes, comparisons were made between pan evaporation and lysimeter ET, pan evaporation and potential ET from the irrigation scheduling program, and lysimeter ET and computed ET from the scheduling program for alfalfa.

TABLE 24. COMPARISON OF ELECTRICAL CONDUCTIVITIES FOR THREE EXTRACT RATIOS OF SOIL SAMPLES FROM TWO TREATMENT PLOTS

Treatment	Depth in.[1/]	Electrical Conductivity mmho/cm 1:0.4	1:1	1:5	(1:5)x12.5*
5N1	0-3	1.84	1.03	.44	5.50
	3-6	1.72	1.00	.38	4.75
	6-9	1.90	1.11	.39	4.88
	9-12	2.05	1.20	.40	4.94
	12-15	3.60	3.00	1.00	12.50
	15-18	3.95	3.10	1.22	15.31
	18-21	4.10	3.45	1.70	21.25
	21-24	4.05	3.35	1.52	18.94
	24-27	4.50	3.60	2.25	28.12
	27-30	4.55	3.45	1.52	18.94
	30-33	5.30	4.30	2.50	31.25
	33-36	5.65	4.30	2.75	34.38
9S2	0-3	3.10	1.62	.48	6.00
	3-6	1.60	.88	.30	3.75
	6-9	1.40	.77	.28	3.56
	9-12	1.39	.80	.28	3.50
	12-15	1.40	.82	.29	3.62
	15-18	1.60	.95	.32	3.94
	18-21	1.60	.96	.30	3.75
	21-24	2.20	1.25	.38	4.75
	24-27	3.15	2.00	.66	8.25
	27-30	3.20	2.15	.76	9.50
	30-33	3.25	2.49	.92	11.50
	33-36	3.35	2.50	1.04	13.00

*This column adjusts the conductivity of the 1:5 extract to the comparable moisture content of the 1:0.4 extract.

[1/] 1 inch = 2.54 cm.

Figure 25 compares the cumulative seasonal lysimeter ET for alfalfa with cumulative seasonal pan evaporation. Figure 26 gives the approximate pan coefficients (crop ET divided by pan evaporation) during the season. The wide scatter in points is due to the fluctuation in lysimeter readings caused by the sticking problem mentioned under procedures. The curves in Figure 26 are average lines that approximate the true pan coefficients. The high values that occurred just prior to each cutting appear to be about 1.2. Crop ET is not normally expected to be higher than pan evaporation for such extended periods of time.

The location of an evaporation pan has an influence on the amount of water evaporated from it. In this case, the pan was situated in the middle of a fully irrigated alfalfa field. Although the alfalfa was clipped in the standard pan enclosure area, the location is not entirely representative of normal evaporation pan locations. Since the pan was completely surrounded by a crop that is transpiring water into a relatively wet atmosphere, it is expected that the pan evaporation would be somewhat less than that of more typical installations.

Figure 27 compares pan evaporation to the potential ET calculated by the irrigation scheduling program. If it is assumed that pan evaporation is equal to the potential ET for the area, then the program under-predicted potential ET consistently throughout the season by about 8 percent. The weather information used in the program was collected in the same location as the pan evaporation data, so if the assumption that pan evaporation is the same as potential ET is correct, the calculated potential ET should have corresponded to pan evaporation. However, the discussion of pan evaporation and lysimeter ET given above would indicate that the pan evaporation for this location was somewhat below "potential ET." If this is true, then the under-prediction of potential ET by the computer program was even greater than the 8 percent shown.

Figure 28 compares lysimeter ET to the empirical ET calculated by the scheduling program. The correspondence is even less favorable than that between pan evaporation and potential ET. At the beginning of each growth period following harvest, the program predicts ET very closely. As the plants develop and ET increases, the predicted ET becomes less and less accurate, with the largest deviation generally occurring just prior to cutting. This is reasonable after looking at the limits in the computer program and at the pan coefficients in Figure 26. The maximum pan coefficient is 1.2 while the program limits the pan coefficient to 1.0. The net result is an under-prediction of ET of 16 percent.

Since the Jensen irrigation scheduling program was originally calibrated for standard Weather Bureau reporting stations, it was decided that a comparison should be made between the weather data collected at the research location and that reported by the weather station at the Vernal airport located approximately one mile north of the research farm. It was found that the daily maximum and minimum temperatures were higher at the airport than at the farm, so the scheduling program was rerun using the airport temperatures. Figure 29 compares the results of that computation with lysimeter ET. A

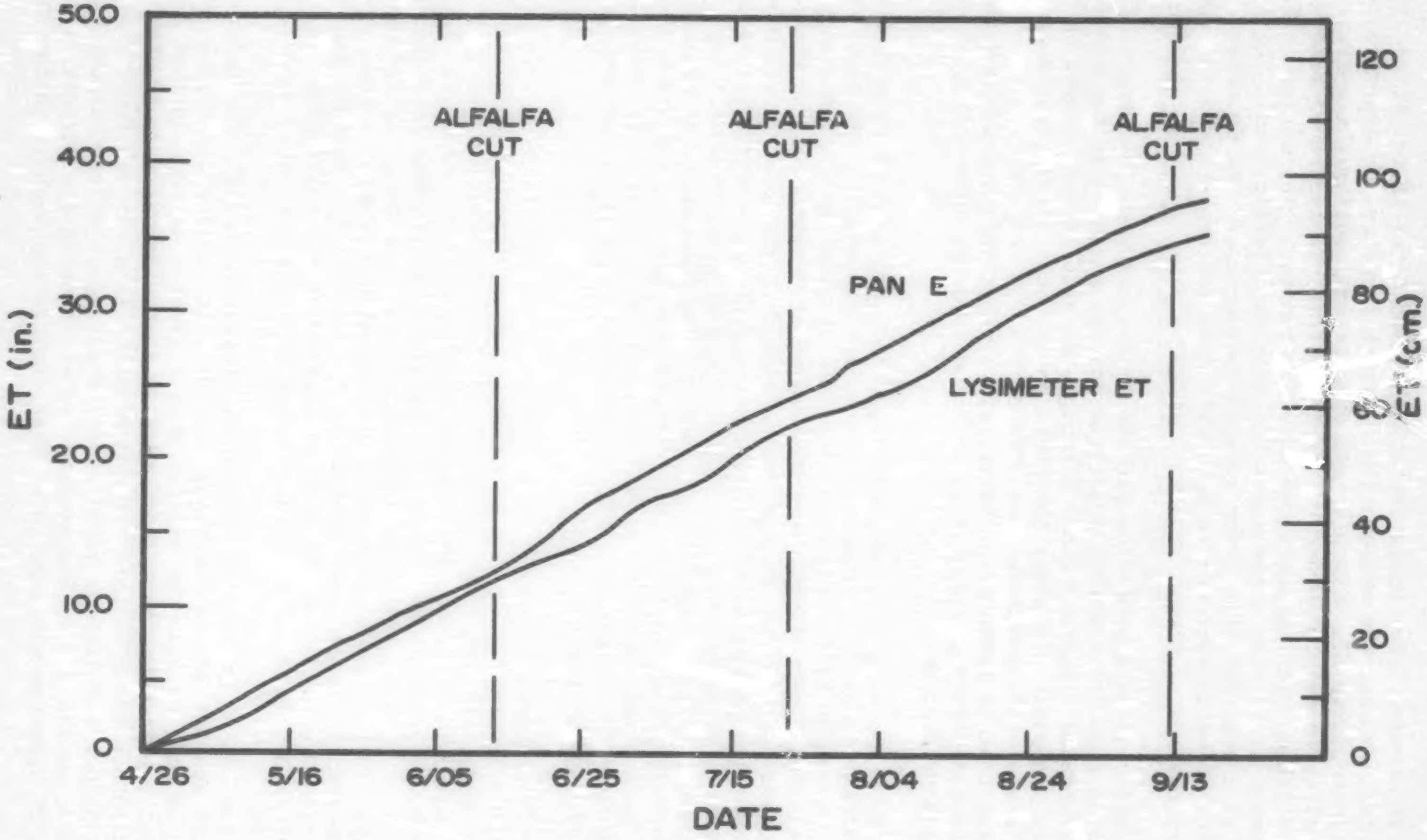


Figure 25. Cumuiative lysimeter ET for alfalfa and pan evaporation.

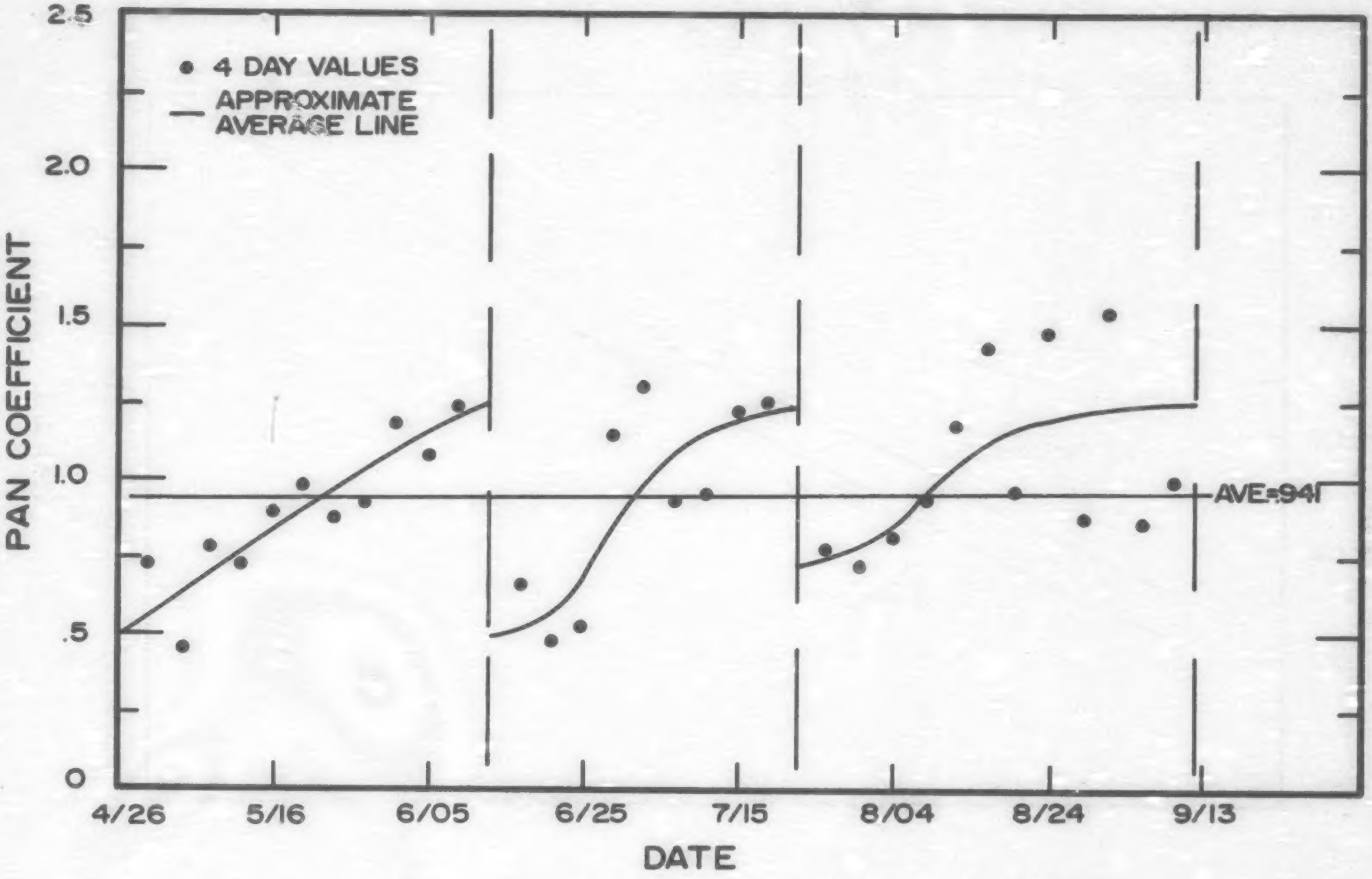


Figure 26. Approximate 4-day average pan coefficients (ET alfalfa/E pan) for alfalfa.

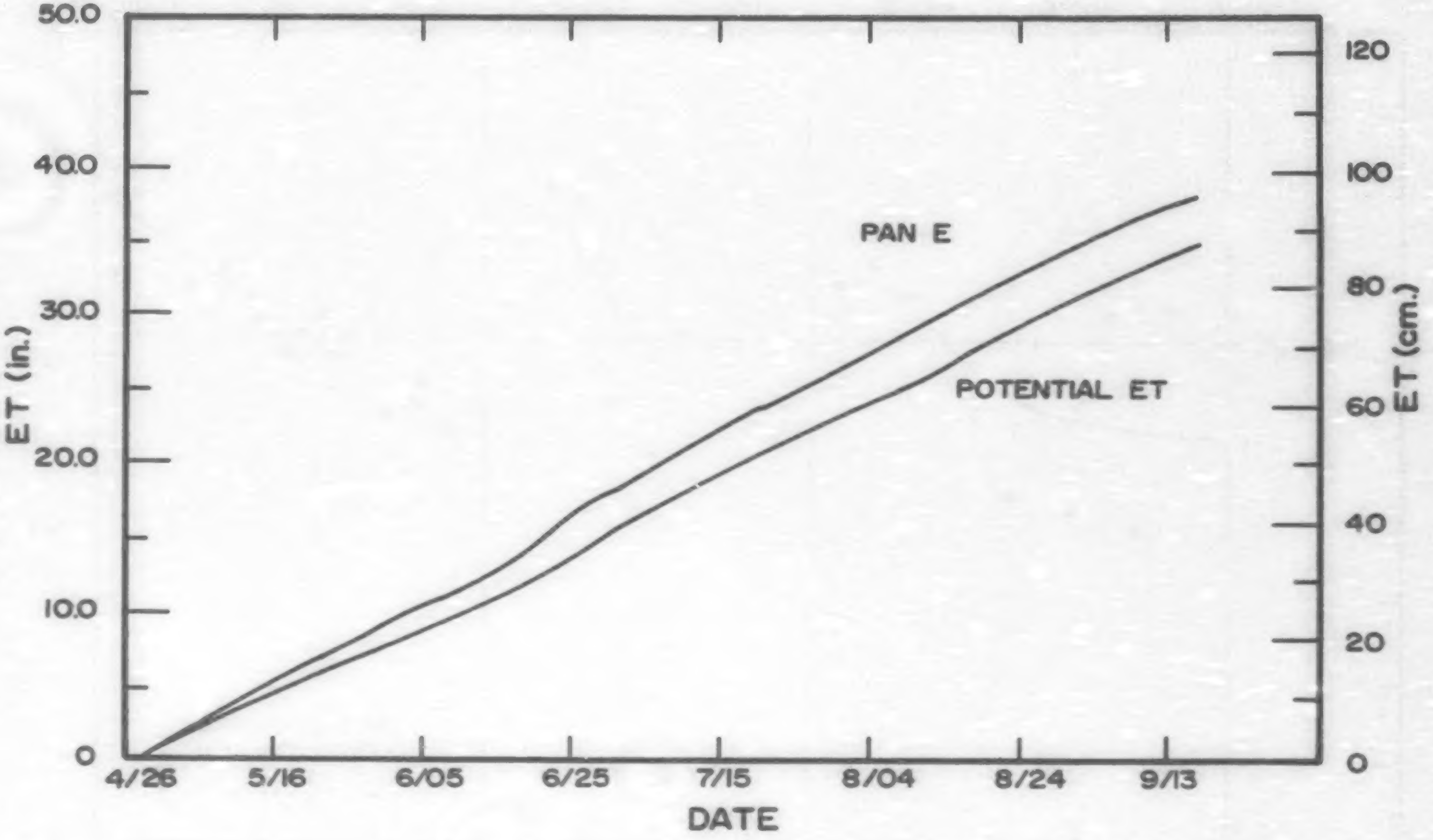


Figure 27. Cumulative pan evaporation and potential ET.

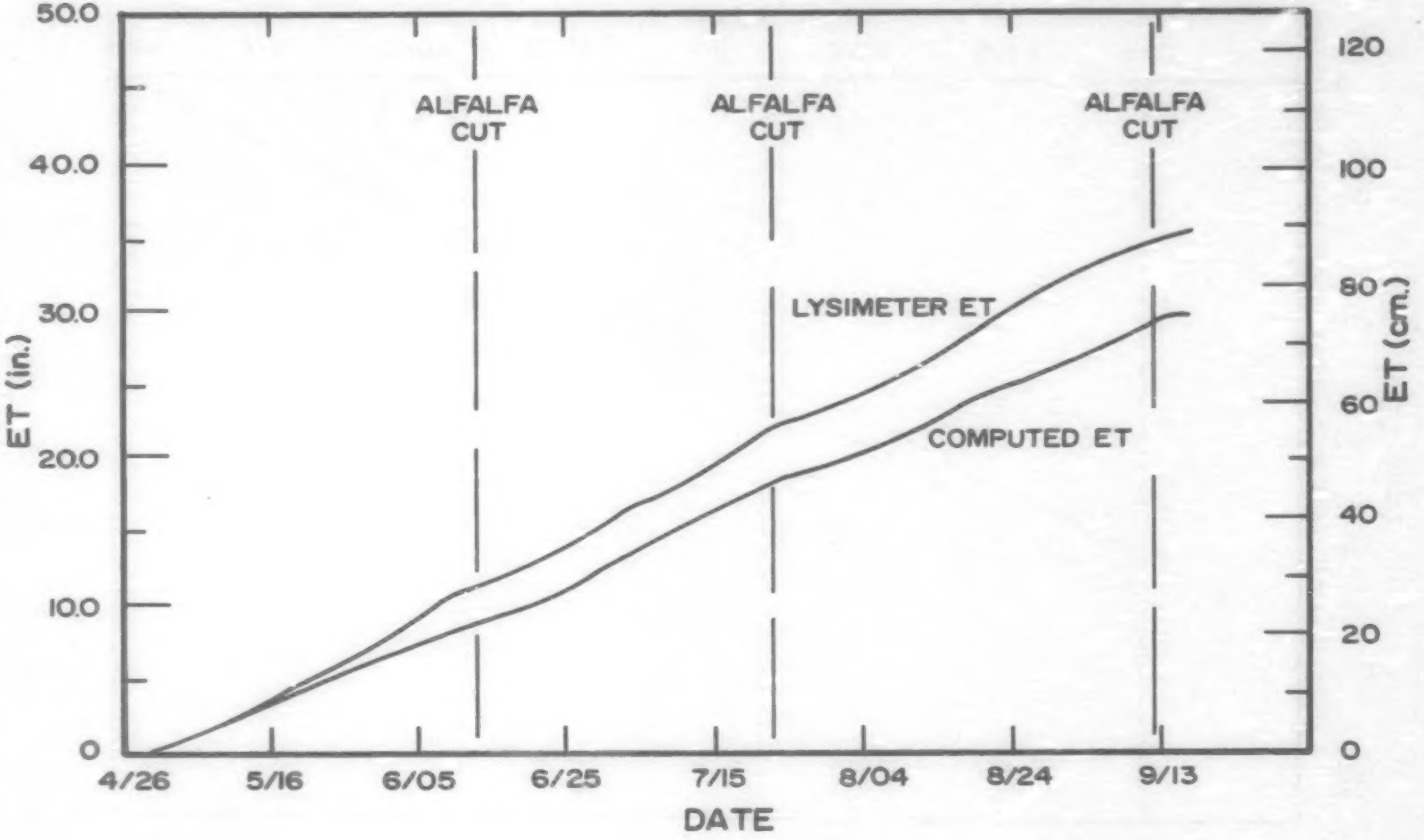


Figure 28. Cumulative lysimeter ET and computed ET for alfalfa using Jensen irrigation scheduling program.

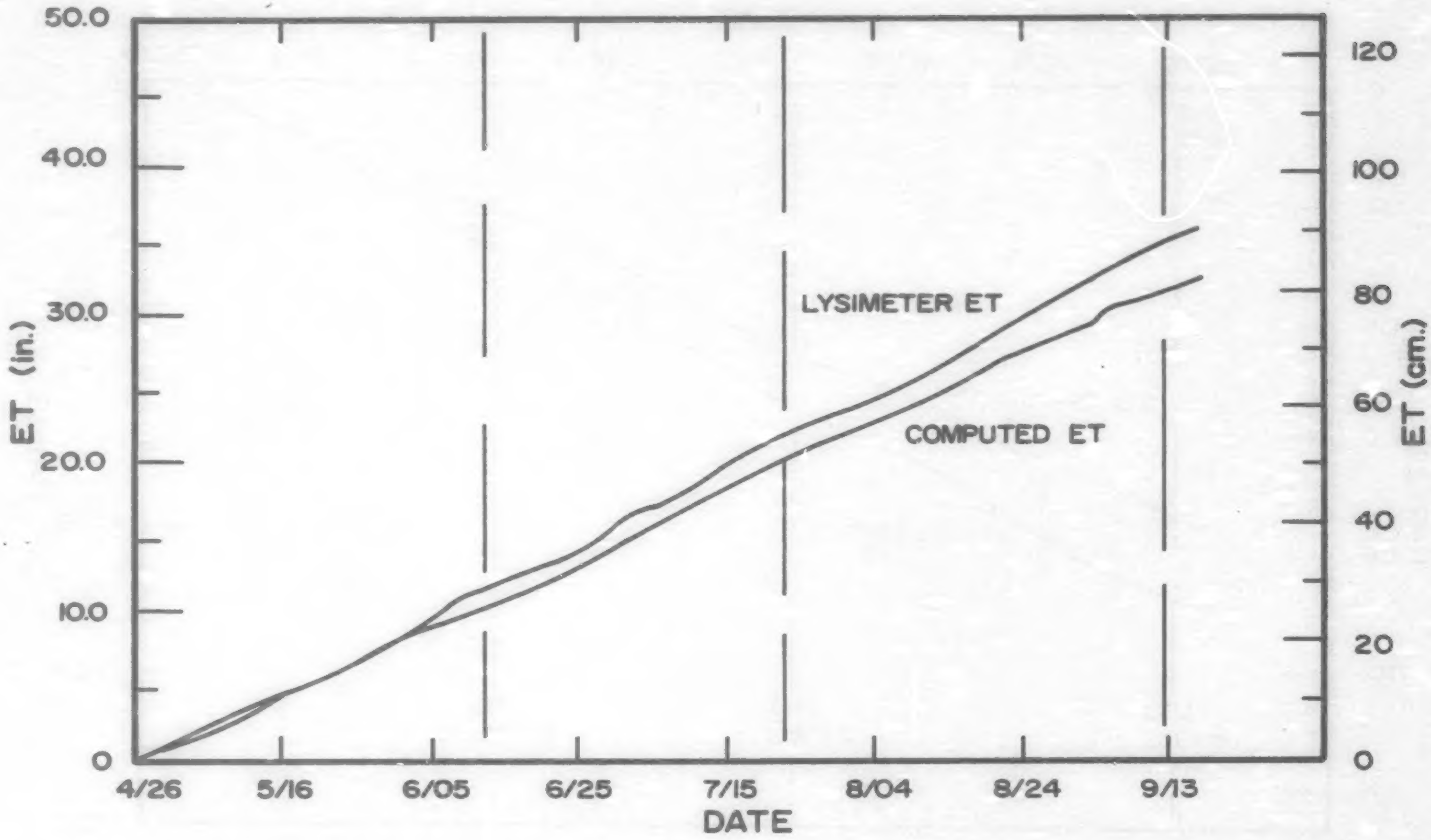


Figure 29. Cumulative lysimeter ET and computed ET using airport temperatures for alfalfa (Jensen irrigation scheduling program).

definite improvement was made in the values of predicted ET. The predicted ET was only 8.6 percent lower than the lysimeter ET. It is expected that if dew point temperatures from the Vernal airport were available, they would also be lower than those for the farm, which would further improve the prediction.

With enough manipulation of data it would be possible to predict the lysimeter ET for this one season exactly. However, by looking at Figure 30, which compares the cumulative measured ET of the two lysimeters, it is obvious that it is not reasonable to expect to be able to predict ET empirically with any more accuracy than about 10 to 15 percent, since the direct measurement of ET varied 11.5 percent between the two lysimeters. From the data shown, it is also apparent that the location at which the weather information is collected can play a very important role in the accuracy of the predicted ET.

Sprinkler System Evaluation

Results of the can-catches for single irrigations for the solid-set sprinkler irrigation system used on the farm outside the plots are summarized in Tables 25 and 26. The coefficient of uniformity, Cu, is defined by Equation [4]. The low quarter potential irrigation efficiency, PE is defined by equation [5]. The low quarter distribution uniformity, Du_{1q} is defined by Equation [6]. The low catch distribution uniformity, Du_{1c}, is defined by Equation [7].

The average operating pressure for all tests was 60 p.s.i. (4.22 kg/cm^2). The average wind velocity for each catch ranged from 1.27 miles per hour (0.57 m/s) to 5.45 miles per hour (2.44 m/s) with an overall average of 2.53 miles per hour (1.13 m/s). The wind direction for each irrigation was west-southwest. Wind speed in the range shown did not seem to have a significant effect on uniformity of water distribution.

Table 25 shows the individual irrigation uniformities, but what is of practical importance is the progressive composite performance shown in Tables 27 and 28 for the system over an irrigation season. An improvement in both Cu and Du with time occurred. The greatest improvements were in the values of Du.

Table 29 gives the computed composite uniformities and efficiencies synthesized for the system assuming every other irrigation was an alternate set. An improvement was seen both with seasonal compositing and alternate setting.

In irrigation management to control leaching, the important system parameter is the distribution uniformity. In order to avoid a salt buildup somewhere in the field, the minimum desired leaching fraction must be attained at every point in the field. Therefore, if the Du_{1c} is 80 percent and the desired minimum leaching percentage is 0.0, the average leaching percentage for the field would have to be 20 percent to have zero leaching in the low

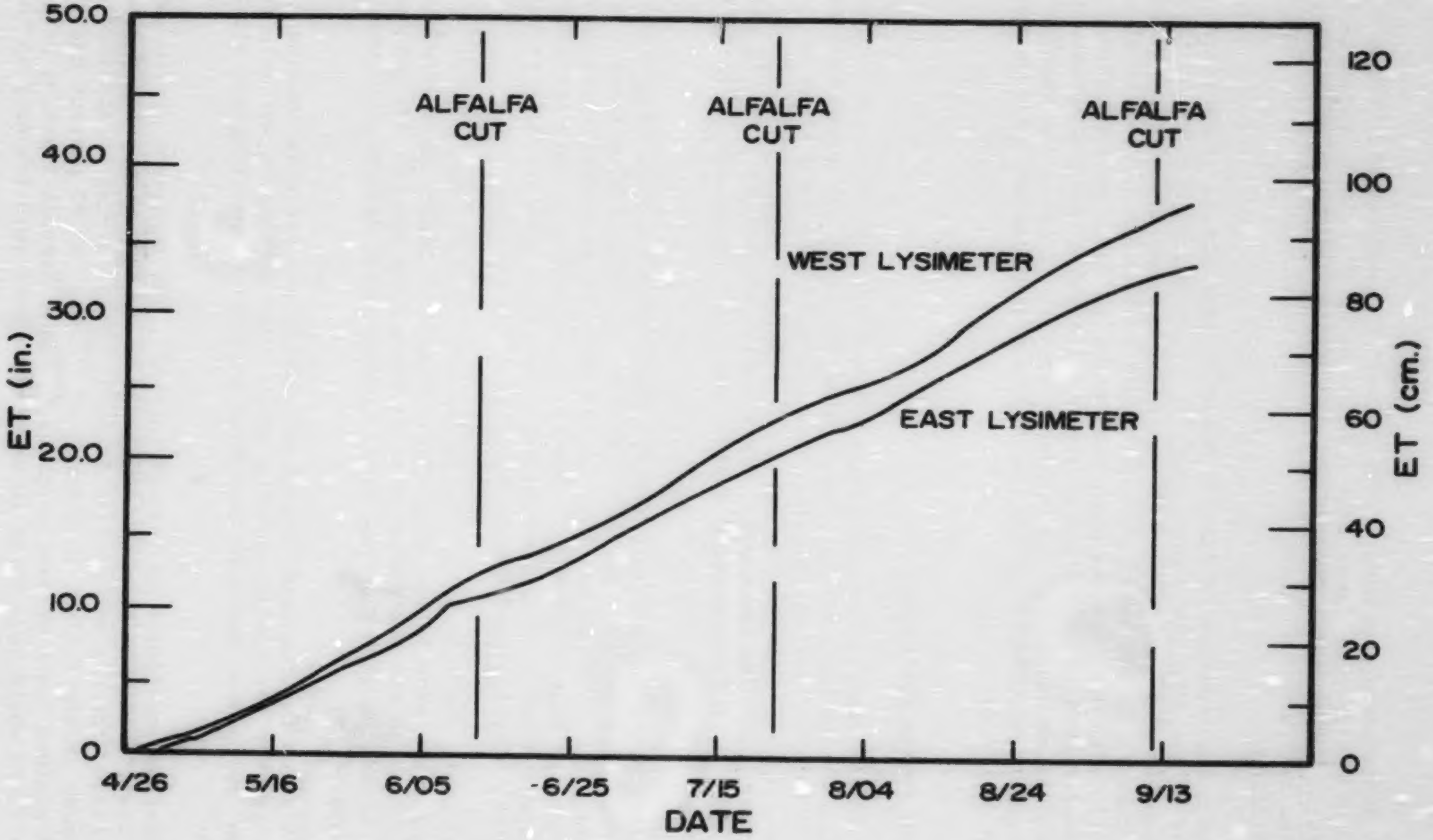


Figure 30. Cumulative ET for alfalfa from east and west lysimeters.

TABLE 25. SPRINKLER SYSTEM PERFORMANCE PARAMETERS FOR SINGLE IRRIGATIONS USING #30 RAINBIRD SPRINKLERS WITH 9/64 IN. (3.6 MM) NOZZLES ON 30 FT x 50 FT[1/] SPACING

Date	Depth Applied	Av Depth Caught D_c	Av Depth Low 1/4 C_{1q}	Low Catch C_1	Cu	PE Low 1/4	Du_{1q} Low 1/4	DU_{1c} Low Catch
06/05/74	5.17	4.70	3.80	3.57	86.	74.	81.	76.
06/23/74	3.19	3.07	2.53	2.39	88.	79.	82.	78.
07/04/74	3.18	2.84	2.49	2.33	92.	78.	88.	82.
07/17/74	3.86	3.64	2.92	2.58	87.	76.	80.	71.
08/02/74	4.16	3.93	3.53	3.38	94.	85.	90.	86.
08/14/74	3.19	2.99	2.63	2.43	91.	82.	88.	81.
08/24/74	4.93	4.75	4.01	3.65	89.	81.	84.	77.

[1/] 1 foot = 0.305 m

TABLE 26. SPRINKLER SYSTEM PERFORMANCE FOR SINGLE APPLICATIONS USING #20 HILO RAINBIRD SPRINKLERS WITH 5/32 IN. NOZZLES IN 25 FT X 30 FT SPACING[1/]

Date	Depth Applied	Av Depth Caught D_c	Av Depth Low 1/4 C_{1q}	Low Catch C_1	Cu	PE Low 1/4	Du_{1q} Low 1/4	Du_{1c} Low Catch
08-07-75	2.18	1.98	.925	.69	73.	43.	47.	35.
08-13-75	3.05	2.496	1.725	1.26	79.	56.	69.	50.

[1/] 1 foot = 0.305 m

TABLE 27. SPRINKLER SYSTEM PERFORMANCE COMPOSITED TO DATE FOR #30 RAINBIRD SPRINKLER WITH 9/64 IN. (3.6 MM) NOZZLE ON 30 FT X 50 FT[1] SPACING

Date	Depth Applied	Av Depth Caught Dc	Av Depth Low 1/4 C_{1q}	Low Catch C_1	CU	PE Low 1/4	Du_{1q} Low 1/4	Du_{1c} Low Catch
06/05/74	5.17	4.70	3.80	3.57	86.	74.	81.	76.
06/23/74	8.36	7.77	6.48	6.19	87.	78.	83.	80.
07/04/74	11.54	10.61	9.21	8.89	90.	80.	87.	84.
07/17/74	15.39	14.25	12.50	11.93	91.	81.	88.	84.
08/02/74	19.55	18.18	16.51	15.79	94.	84.	91.	87.
08/14/74	22.74	21.17	19.22	18.39	93.	85.	91.	87.
08/24/74	27.67	25.92	23.51	22.60	94.	85.	91.	87.

[1] 1 foot = 0.305 m

TABLE 28. SPRINKLER SYSTEM PERFORMANCE COMPOSITE TO DATE FOR #20 HILO RAINBIRD SPRINKLER WITH 5/32 IN. NOZZLE ON 25 FT X 30 FT[1] SPACING

Date	Depth Applied	Ave Depth Caught Dc	Av Depth Low 1/4 C_{1q}	Low Catch C_1	CU	PE Low 1/4	Du_{1q} Low 1/4	Du_{1c} Low Catch
08-07-75	2.18	1.98	.925	.69	73.	43.	47.	35.
08-13-75	5.23	4.482	2.88	1.99	78.	55.	64.	44.

[1] 1 foot = 0.305 m

TABLE 29. SPRINKLER SYSTEM PERFORMANCE WITH SIMULATED COMPOSITED ALTERNATE SETS FOR #30 RAINBIRD SPRINKLER WITH 9/64 IN. (3.6 MM) NOZZLE ON 30 FT X 50 FT[1] SPACING

Date	Depth Applied	Av Depth Caught Dc	Av Depth Low 1/4 C_{1q}	Low Catch C_1	Cu	PE Low 1/4	Du_{1q} Low 1/4	Du_{1c} Low 1/4
06/05/74	5.17	4.70	3.80	3.57	86.	74.	81.	76.
06/23/74	8.36	7.77	7.11	6.90	95.	85.	91.	89.
07/04/74	11.54	10.61	10.11	9.87	97.	88.	95.	93.
07/17/74	15.39	14.25	13.24	12.83	95.	86.	93.	90.
08/02/74	19.55	18.18	17.19	16.90	97.	88.	95.	93.
08/14/74	22.74	21.17	20.07	19.73	97.	88.	95.	93.
08/24/74	27.67	25.92	24.95	23.95	98.	90.	96.	92.

[1] 1 foot = 0.305 m

quarter application area. If the Du_{lc} is 92 percent and the desired leaching percentage is 0.0, the average leaching percentage for the field would be 8 percent. In other words, the average attainable leaching fraction varies inversely with Du.

In evaluating a sprinkler system for leaching control, it is necessary to know the minimum depth applied in relation to the average depth applied to the entire field. In operation, the pressure and therefore the sprinkler nozzle discharge varies over the field. Under strict management or automation it is possible to operate a sprinkler system so that the supply end of all the laterals would operate at the same pressure. If the standard 20 percent friction loss in the lateral is used, then the pressure at the first outlet is approximately 1.2 times the pressure at the last outlet. From Keller and Karmeli (1974) for multiple outlet lines

$$H_m = H_A + R_h \Delta H_m \pm \frac{EL}{2} \qquad [15]$$

where

H_m = line inlet pressure head

H_A = average line pressure

R_h = headloss adjustment = .77 for single size line

ΔH_m = headloss in line = 0.2 H_m

EL = change in elevation = 0.0 for this situation

H_D = end pressure head

rearranging and substituting

$$H_A = 1.2\ H_D - .77\ (.24\ H_D) \qquad [16]$$

$$H_A = 1.02\ H_D$$

and since Q varies with the square root of H

$$Q_A = 1.01\ Q_D \qquad [17]$$

where

Q_A = average outlet discharge

Q_D = discharge of last outlet

In other words, the average discharge is 1.0 percent higher than the end discharge. If, as before, the low catch distribution efficiency is 91 percent and the desired minimum leaching percentage is 0.0, then the average leaching percentage for the field would be 10 percent. That means that for the solid-set sprinkler system on the farm, operated on an alternate set basis, the minimum leaching percentage attainable without actually under-irrigating some area is 10 percent. If some leaching is maintained, say 3 percent, then the minimum average leaching percentage required for the farm is 13 percent.

Alfalfa Yield Response

Detailed measurements of yield were taken for two alfalfa cuttings in 1974 and for three cuttings in 1975. The complete data are shown in Table 30. The deep water table plots were not included in the 1975 experiments. A statistical analysis of the data from the factorial experimental design showed significance for water table depth and water quality treatments, but not for the leaching fraction treatment. The deepest water table and the highest quality water gave the highest yields. Table 31 shows data averaged by treatments for 1975. The lowest leaching fraction showed the highest yield among those treatment averages. For the two year duration of this experiment, there was no significant treatment effect of leaching fraction on yield even at the 10 percent level by the F test.

CROP GROWTH AS INFLUENCED BY SOIL SALINITY

1974 Corn Results

Irrigation - The funnel sampling system demonstrated the line source sprinkler system to be effective in establishing the continuous but uniformly variable water treatments (Figure 31). Total amounts of water applied ranged from 17.7 inches (45.0 cm) at water level one (W1) to 1.7 inches (4.2 cm) at W20. Wind proved to be a major problem associated with the irrigation system. As a result, irrigation was conducted only in the early mornings and some late afternoons when wind speed was low. This schedule resulted in less water being applied than had been desired, but it maintained the continuous variable water treatment.

Soil Water Content - The soil water content measured with a neutron probe show that soil water decreased very little on any treatment. Neither irrigation treatment nor salt levels had any appreciable effect on the water content (Figures 32 and 33). Readings taken as late as September 18, 1974, showed high water contents in all the treatments. Upward flow from a water table at about 7 feet (2.13 m) was the most likely source of the water causing the water contents to stay high, since total natural precipitation was only 0.5 inches (1.27 cm) for the entire growing season. This plot was originally chosen because the water table was deeper than at any other place on the Vernal farm, but apparently the amount of water movement upward from the water table was still significant.

Salinity

In the application of salt to control the osmotic potential, intentions were to evenly distribute the salt in the top two feet (60 cm) of soil. Achieving this would have resulted in the approximate desired osmotic potential of each treatment (Table 2). However, soil samples taken before the first irrigation showed the salt to be somewhat unevenly distributed in the top

TABLE 30. ALFALFA DRY MATTER YIELDS FROM 1974 AND 1975 WATER MANAGEMENT EXPERIMENTS IN VERNAL, UTAH

	Dry matter yields metric tons/hectare[1/]				
Treatment	7/23/74	8/11/74	6/26/75	8/1/75	9/15/75
5A1	5.77	4.70	8.02	6.03	5.35
5A2	4.99	4.39	5.27	5.14	4.35
5A3	5.48	4.39	5.75	5.83	3.11
5N1	5.05	4.50	4.33	4.16	3.47
5N2	4.69	4.39	2.78	4.76	4.06
5N3	4.45	4.34	2.91	4.88	4.46
5S1	3.85	4.45	5.13	3.33	3.74
5S2	4.56	4.58	5.27	3.24	3.30
5S3	4.56	4.45	3.56	3.20	2.99
7A1	4.94	4.94	6.58	5.41	4.54
7A2	5.18	5.26	5.72	6.86	4.57
7A3	5.10	4.94	5.67	6.02	4.00
7N1	4.45	4.58	5.21	5.41	5.08
7N2	4.86	4.45	5.27	5.52	5.33
7N3	5.34	4.88	5.18	4.33	4.23
7S1	3.61	4.20	3.37	6.44	5.61
7S2	4.69	4.50	4.29	3.61	4.58
7S3	4.94	4.77	4.86	3.57	4.01
9A1	3.55	3.42	--	--	--
9A2	2.88	3.15	--	--	--
9A3	2.58	2.77	--	--	--
9N1	3.58	3.20	--	--	--
9N2	3.47	3.47	--	--	--
9N3	3.17	3.42	--	--	--
9S1	3.07	2.60	--	--	--
9S2	3.72	2.93	--	--	--
9S3	3.80	3.15	--	--	--
Average	4.31	4.10	4.95	4.87	4.26

[1/] 0.45 x metric tons/ha = tons/ac.

TABLE 31. AVERAGE DRY MATTER ALFALFA YIELDS FOR THREE CUTTINGS IN 1975

Treatment	Yield metric tons/hectare[2]
5 foot[1] water table (5)	4.38
7 foot[1] water table (7)	5.01
High Quality Water (A)	5.46
Middle Quality Water (N)	4.52
Low Quality Water (S)	4.12
Low Leaching Fraction (1)	5.07
Middle Leaching Fraction (2)	4.66
High Leaching Fraction (3)	4.26

[1] 1 foot = 0.305 meters

[2] 0.45 x metric tons/ha = tons/acre.

18 inches (46 cm) of soil. This concentration of salt was one of the factors that may have made a second planting necessary, although seedling emergence in the whole agricultural area was generally poor.

The tractor and fertilizer spreader proved to be a relatively easy method of applying the salt but may have caused a serious soil compaction problem. Since higher salt application required more trips across the plots with the tractor and drill, the compaction problem in turn caused an infiltration problem in the high salinity plots that may have affected germination. There was noticeable difficulty getting the irrigation water into the soil without runoff. It was necessary to irrigate for a shorter duration more frequently.

The salt became more evenly distributed in the soil profile with time. Electrical conductivities of the soil samples taken just before harvest showed the salt to be relatively uniformly distributed to a depth of 3 feet (0.9 m). The higher water application levels leached the salt slightly deeper and distributed it somewhat more evenly.

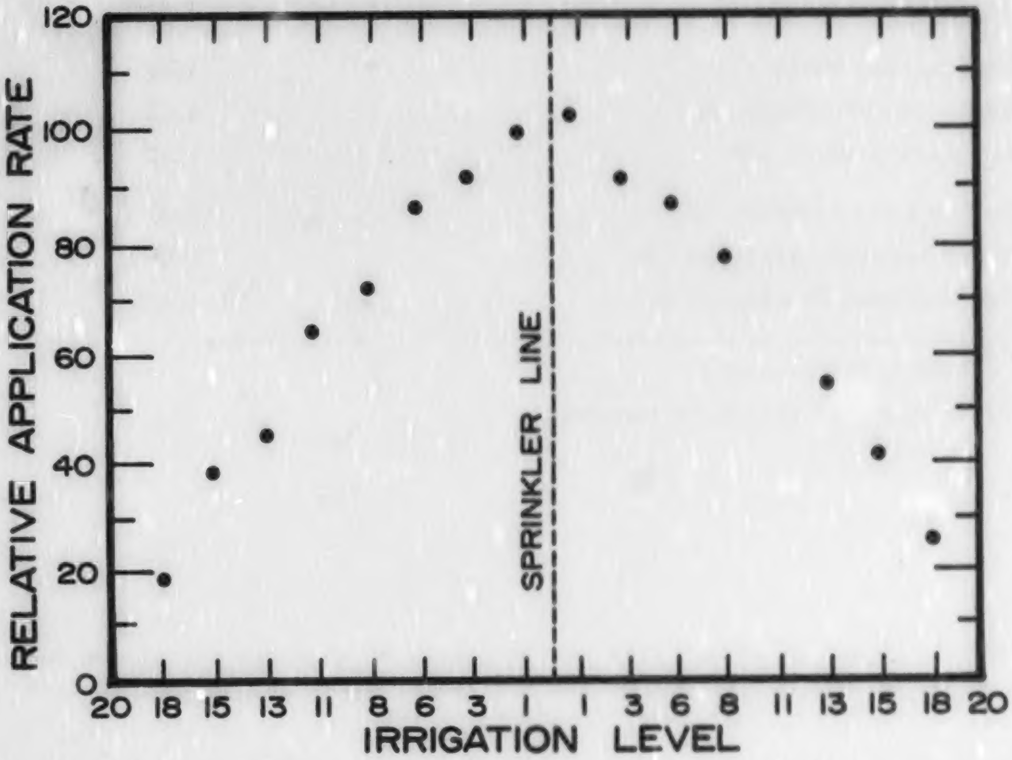


Figure 31. Relative sprinkler application rate as a function of distance from the sprinkler line.

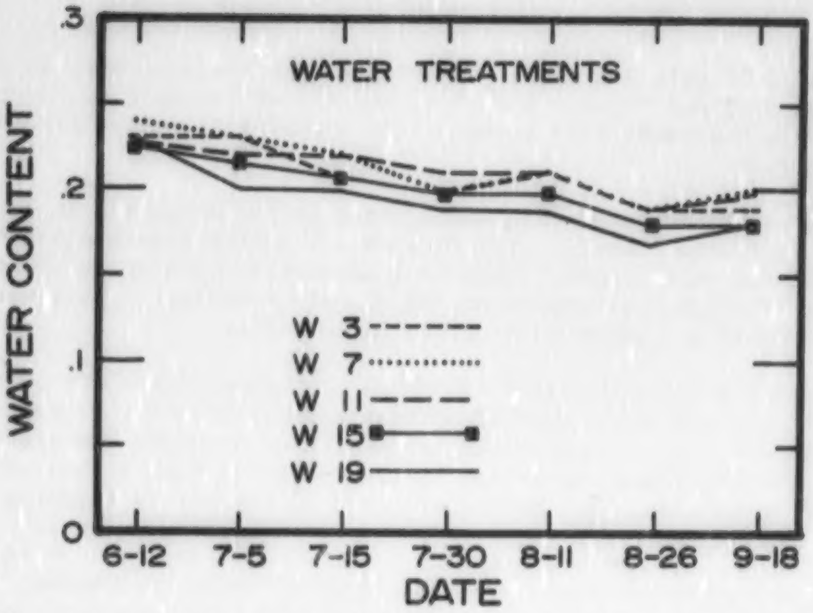


Figure 32. Average volumetric water content in the 1-3 feet (0.3 - 0.9 m) zone during the growing season, 1974.

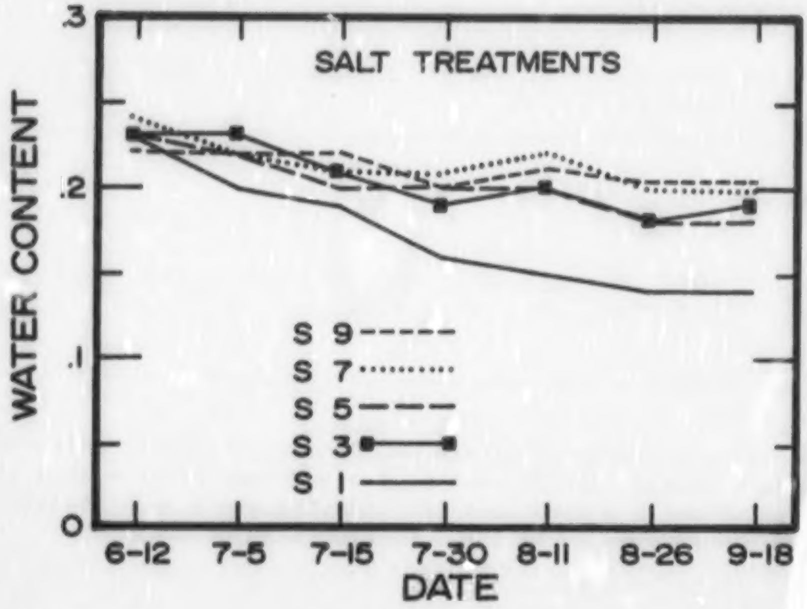


Figure 33. Average volumetric water content in the 1-3 feet (0.3-0.9 m) zone during the growing season, 1974.

Yield

The detailed yield data and their resulting graphs are presented in Tables B-1, B-2, and B-3, and Figures B-1, B-2, and B-3 of Appendix B. Oven dry matter has been expressed both as Kg/ha and grams/plant to isolate the compaction effect.

Figure 34 shows the average grain and dry matter yield plotted as a function of salt and irrigation levels. The data show a nearly linear relationship between yield and salt levels. There was not nearly as much influence on yield due to irrigation treatment as due to salt treatment. This was probably due to water coming up from the water table.

Dry matter yield on an area basis showed an 83 percent reduction over the range of salt applied and showed 52 percent reduction over the range of irrigation levels. Dry matter yield was expressed as grams per plant to correct for the low plant population in the compacted high saline areas. Expressed as grams/plant, dry matter declined 67 percent in response to salt and 56 percent in response to water application level. Grain production declined 96 percent over the range of salt applied. A 64 percent grain yield reduction was found over the range of water treatments.

The effect of compaction on yield is seen in Figure 35. The yield expressed as grams/plant has been equated to that of Kg/ha by a correction factor. The difference in slope of the lines is due to decreased dry matter production of plants growing in the compacted area and a fewer number of plants in the heaviest salt treatments (Table 32).

TABLE 32. AVERAGE NUMBER OF PLANTS PER PLOT ROW AS A FUNCTION OF SALT AND IRRIGATION TREATMENTS.

Salt level	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Average number of plants	10	9	10	10	9	9	9	5	6	4
Water level	W1	W3	W5	W7	W9	W11	W13	W15	W17	W19
Average number of plants	9	9	8	9	9	8	8	7	7	7

Although the average number of plants did not significantly decrease in the first seven salt levels, the dry matter produced per plant within the compacted area showed a steady decrease starting about salt treatment S3. There were no plants growing in the compacted area of S10.

Monitoring Devices

Limited success was achieved with the salinity monitoring instruments. The EC of the soil solution extract was the only data to give a good measure of

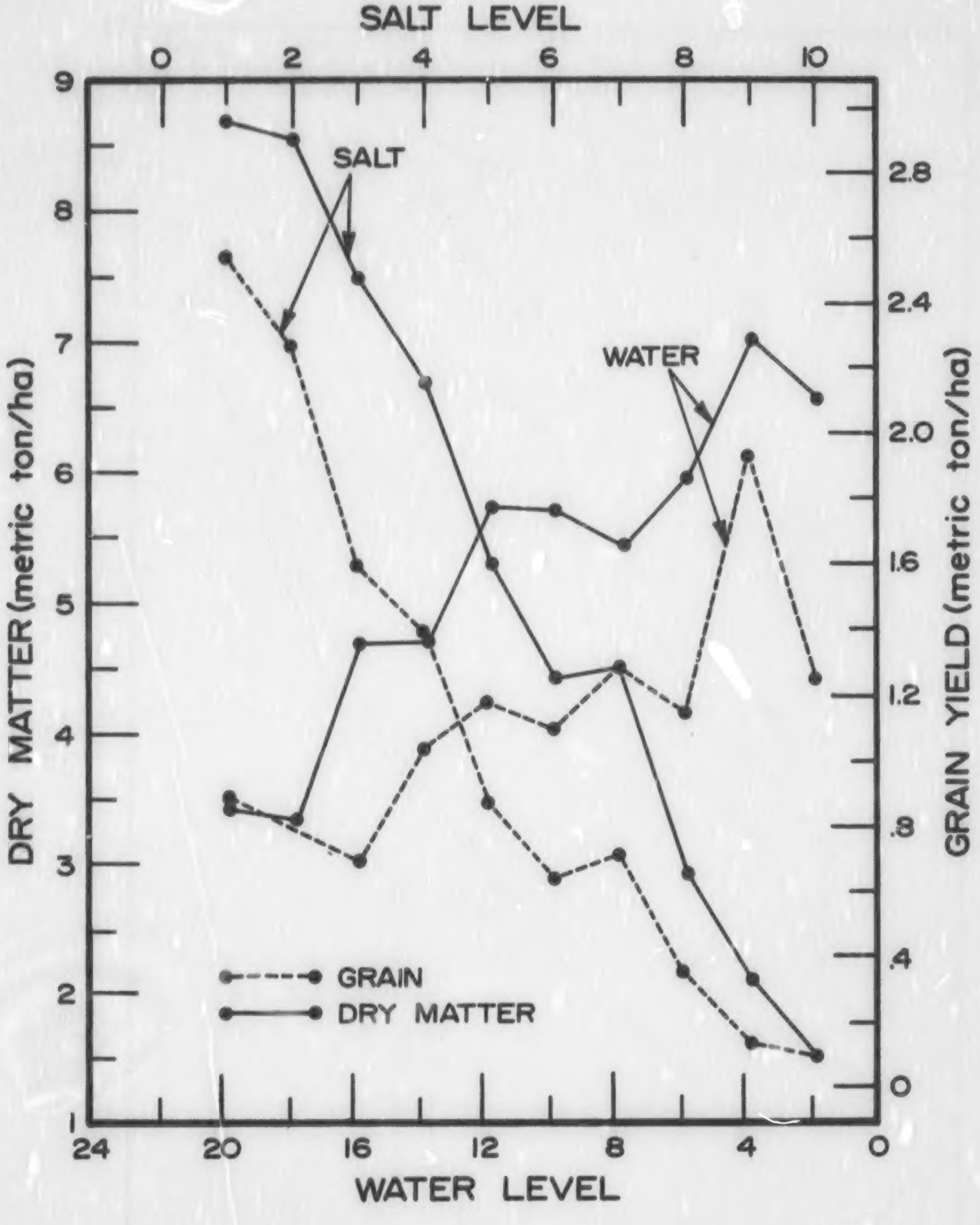


Figure 34. Dry matter and grain yields as influenced by salt and water levels.

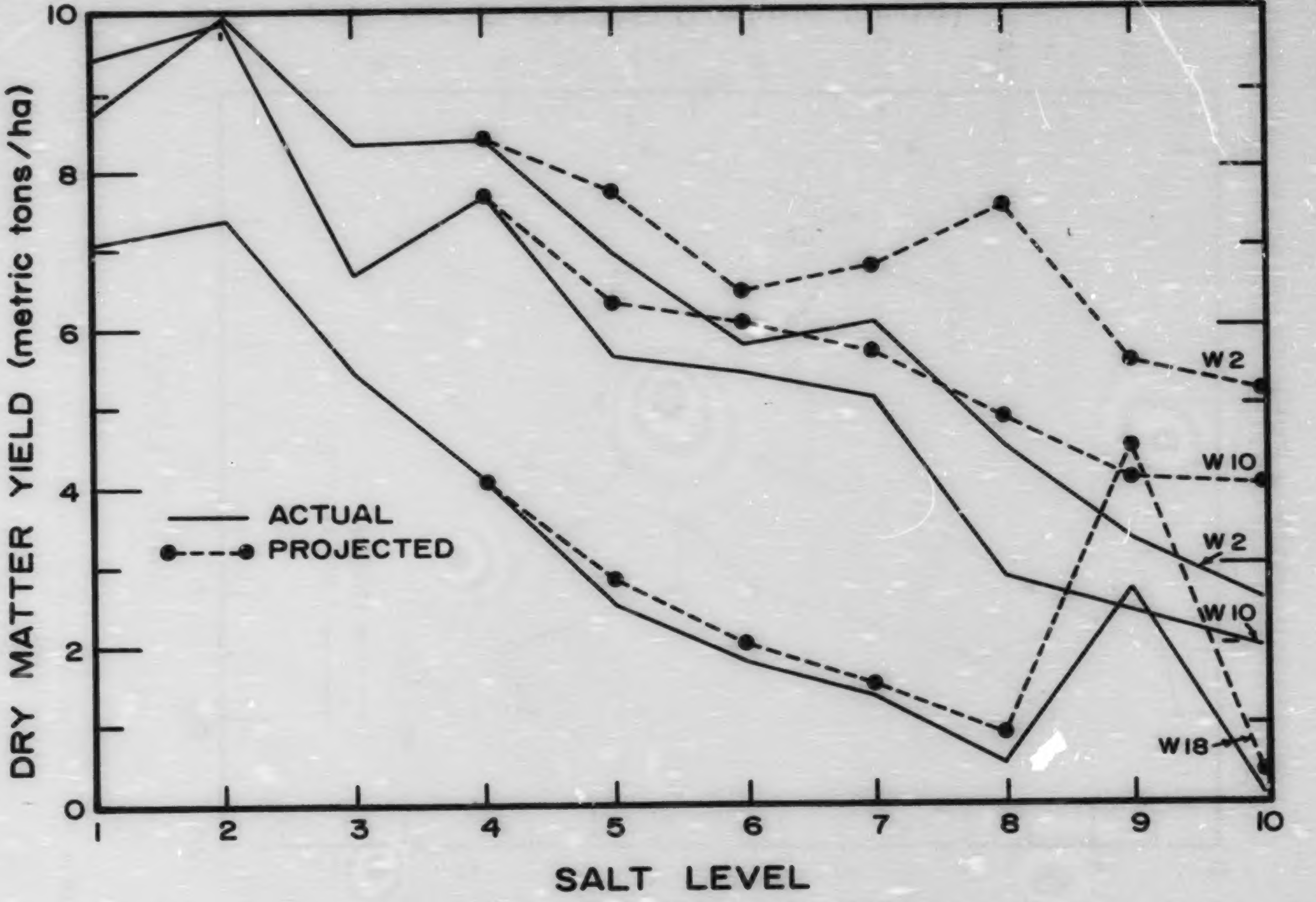


Figure 35. Projected and actual dry matter yields as a function of salt and irrigation levels.

the salinity status of the total soil profile for the course of the growing season.

Salinity sensors - The salinity sensor results were useful in differentiating between the salt and water treatments (Table 33). The salt levels are identified by the magnitude in the readings and the irrigation treatments by the range in the readings over time. The sensors in the high water treatments picked up the movement of the applied salt very early. The lowest water application levels required the entire summer to leach the salt down to one foot (30 cm). Because the salinity sensors were all located at 12 inches, they were insensitive in describing the salinity status of the total soil profile. Their cost prohibited using them in any quantity.

TABLE 33. ELECTRICAL CONDUCTIVITY OF THE SOIL SOLUTION AS MEASURED BY SALINITY SENSORS AS A FUNCTION OF TIME AND SITE AT THE 30 CM DEPTH

Block	Salt level	Water Level	Sampling date 7-15	 7-30	 8-11	 8-24	 9-18
			mmhos/cm at 25°C				
1	1	17	2.4	1.5	1.4	1.2	1.4
	2	15	1.7	7.9	6.0	6.3	5.8
	4	6	7.7	1.4	1.1	0.3	1.6
	0	10	3.7	15.8	13.9	17.0	19.0
2	3	3	5.5	1.0	0.3	0.3	0.3
	3	20	1.2	1.2	1.9	1.6	1.9
	6	14	5.9	4.3	1.7	1.4	2.2
	8	7	3.0	1.1	0.7	0.6	0.3
	8	11	11.7	7.2	7.4		9.2
	8	19	18.0	9.4	9.5	13.5	15.8
3	1	8	1.1	0.5	1.0	0.7	0.3
	2	12	1.9	0.3	0.3	0.3	0.3
	5	18	13.0	13.6	13.2	14.5	12.1
	9	3	4.5	3.5	2.2	3.5	9.8
4	2	16	7.7	7.0		7.7	6.9
	3	9	3.0	1.7	3.0	1.2	1.7
	4	12	10.6	7.7	10.1	10.9	10.9
	5	10	7.7	9.8	11.1	9.9	11.1
	6	7	2.3	4.5	6.4	7.7	
	7	10	12.1	9.7	12.5	9.6	9.6

Thermocouple psychrometers - The thermocouple psychrometer data proved to be of little value. The main problem was obtaining a reliable low value calibration reading at the wet end of the calibration curves. A consistent low reading from the dew point microvolt meter could not be obtained. This made it very difficult to obtain a reliable water potential reading. This also eliminated the usefulness of the psychormeters since most of the readings taken in field were in the lower range. Inasmuch as the water content did not decrease very much during the season, the psychrometer readings would have been changed mostly by salt. Lack of operating experience may also have been a contributing factor.

Resistivity meter - The 4-probe resistivity method (described in Gupta and Hanks, 1972) was used to monitor salt movement and distribution in the profile. The data are presented in Table B-4 of the Appendix B. Problems related to variable soil water content were somewhat minimized by taking the readings just before each irrigation. The water content of the soil just prior to irrigation was relatively constant over the course of the growing season (Figures 36 and 37).

The 4-probe data show the general trend in the distribution of the salt. They do not, however, show the uniformity in distribution that the soil sample data suggest.

The results tend to indicate that the 4-probe was not well suited for routine field use for precision measurements of profile salt distribution. The problem may be due to lack of a reliable water content correction.

Ceramic solution samplers - The ceramic samplers worked well as a means of obtaining soil solutions as long as the units were intact and the soil water content was high. The data collected in the corn plots are shown in Table B-5 in Appendix B. Salt was leached more rapidly and to a greater depth in the high water treatments. The samples taken from the lowest water application levels indicate that it required the entire season to leach the salt to 4 feet (1.2 m).

1975 Corn Results in Vernal

The irrigations applied on the various dates and for different distances from the sprinkler line are shown in Table 34. Also shown are the replication measurements which indicate some of the practical problems of using the line sprinkler source with wind and temporarily clogged sprinklers. There is some variation in application for different irrigations.

The yield data are shown in Table 35. The data show yield decreases that are consistent only for salt levels greater than S8 and for water levels above 17. Thus it appears that there was very little carry-over effect of the salt applied except where water application, and therefore, leaching, was limited. The amount of water applied on level 17 was about 2.8 inches (7 cm) above the rainfall that occurred.

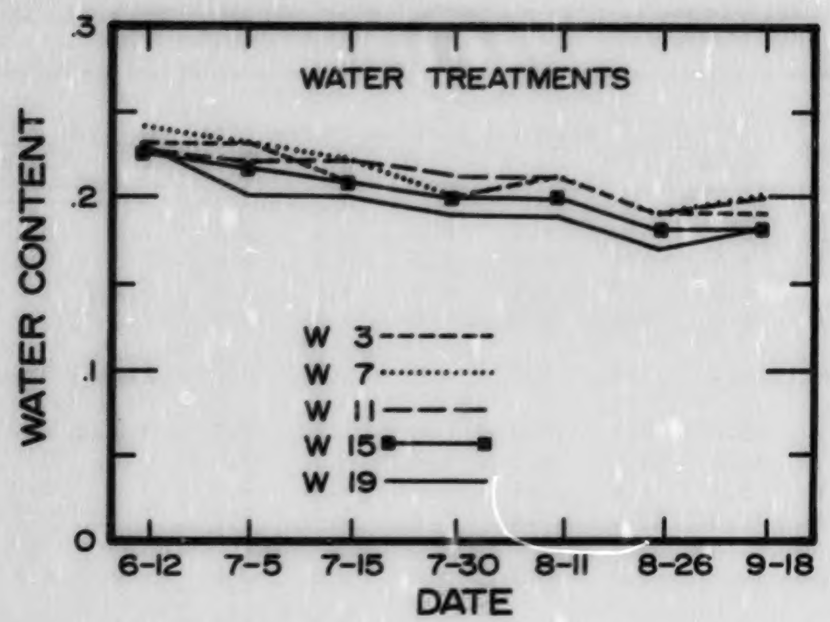


Figure 36. Average volumetric water content in the 1-3 feet (0.3 - 0.9 m) zone during the growing season, 1974.

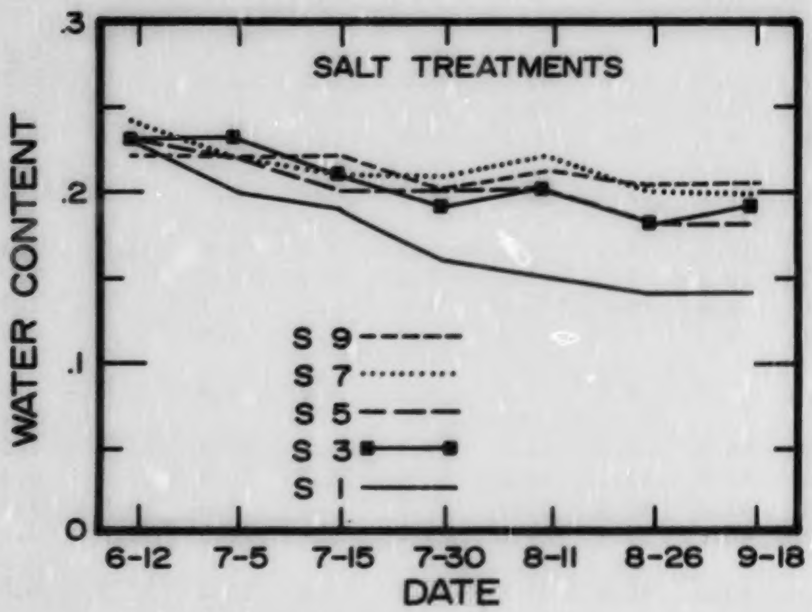


Figure 37. Average volumetric water content in the 1-3 feet (0.3 - 0.9 m) zone during the growing season, 1974.

TABLE 34. IRRIGATION APPLIED AT VERNAL, UTAH, ON THE CORN PLOTS IN 1975

Date	Rep	Distance from sprinkler line - meters								
		0.38	2.21	4.04	5.87	7.70	9.52	11.35	13.18	15.01
						cm				
7-3	A	6.6	6.6	6.6	6.6	4.0	2.3	2.4	0.2	0
	B	6.6	4.8	4.4	4.0	3.3	2.6	1.2	0.8	0
	C	6.6	5.7	4.8	4.6	4.4	4.3	3.1	1.5	0.8
	D	6.5	5.2	4.9	4.5	3.5	2.6	2.2	0.9	0.3
	Ave	6.4	5.6	5.2	4.9	3.8	3.0	2.2	0.8	0.3
7-18	A	12.4	8.3	10.0	6.0	5.6	5.4	3.3	1.4	0.8
	B	11.6	12.5	9.2	4.4	5.2	3.4	2.0	0.5	1.1
	C	9.2	6.4	7.1	6.9	6.0	4.1	3.3	2.0	2.6
	D	10.5	10.0	8.4	6.7	5.4	1.7	1.7	1.0	0.7
	Ave	10.9	9.3	8.7	6.0	5.6	3.6	2.6	1.2	1.3
7-31	A	5.4	5.3	4.8	3.5	3.0	2.8	1.6	1.0	0
	B	6.8	7.1	7.3	5.7	4.8	4.2	2.7	1.1	0.2
	C	5.7	5.4	5.2	4.6	3.1	2.3	1.5	0.3	0
	D	4.9	4.6	3.4	2.7	2.2	1.9	1.1	0.3	0.2
	Ave	5.7	5.6	5.2	4.1	3.3	2.8	1.7	0.7	0.1
8-13	A	11.6	15.0	12.4	7.5	7.6	7.6	5.0	2.4	1.1
	B	10.7	11.6	10.9	6.0	5.6	5.3	3.0	1.8	0
	C	12.9	13.7	12.4	11.0	8.2	9.9	3.9	2.2	0.8
	D	9.2	8.4	6.5	5.6	5.4	4.1	2.4	1.6	0.8
	Ave	11.1	12.2	10.6	7.5	6.7	6.7	3.6	2.0	0.7
8-27	A	10.6	7.5	7.5	5.7	5.0	6.8	3.9	2.3	1.2
	B	10.2	7.3	7.3	7.0	6.8	5.3	3.4	1.9	0.3
	C	6.8	10.0	4.1	4.4	4.1	5.7	2.8	1.0	0.4
	D	9.5	7.6	5.8	3.9	2.7	1.9	1.5	0.8	0.4
	Ave	9.3	8.1	6.2	5.2	4.6	4.9	2.9	1.5	0.6
Totals	A	46.1	42.6	41.2	29.2	25.2	25.6	17.4	7.8	4.0
	B	45.8	43.2	39.2	27.1	25.1	20.8	12.3	6.1	1.5
	C	41.2	41.3	33.6	31.5	25.8	26.4	14.6	7.1	4.6
	D	40.6	35.9	29.0	23.4	19.3	12.2	8.9	4.6	2.4
	Ave	43.4	40.8	35.8	27.8	23.8	21.2	13.3	6.4	3.1

TABLE 35. INFLUENCE OF SALINITY LEVEL IMPOSED IN 1974 ON 1975 CORN DRY MATTER YIELDS AS INFLUENCED BY WATER LEVEL

Water Level	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Ave
					- mt/ha -						
1	22.48	26.41	23.04	27.35	27.53	20.97	18.35	21.36	22.09	20.59	23.02
2	15.28	23.17	16.98	23.77	19.82	20.40	20.00	21.90	21.52	24.17	20.70
3	18.26	20.56	20.55	24.83	27.42	21.32	18.27	19.79	17.11	20.55	20.87
4	19.54	24.13	10.34	12.72	21.82	18.74	17.61	16.47	18.76	21.37	18.15
5	20.22	25.72	18.20	25.44	24.57	26.00	22.24	18.77	14.26	18.49	21.39
6	15.44	23.32	18.07	23.32	22.32	26.24	23.32	21.57	17.49	23.91	21.50
7	21.75	25.28	22.35	21.75	21.16	22.27	20.87	21.71	18.51	21.16	21.68
8	20.15	26.37	20.15	20.68	24.61	23.11	23.71	20.90	15.70	20.15	21.55
9	17.63	26.60	17.80	19.84	19.43	23.91	22.99	19.72	20.32	26.01	20.43
10	17.75	23.77	21.96	22.57	23.17	22.27	18.97	17.75	15.65	17.15	20.00
11	23.62	26.64	22.10	23.61	22.10	27.56	22.71	18.77	15.74	21.80	22.47
12	22.43	22.70	24.12	19.01	16.56	23.32	21.16	17.78	17.18	11.64	19.59
13	21.29	23.11	20.38	21.87	20.63	20.64	21.87	21.48	16.94	18.48	20.67
14	18.65	23.63	20.52	20.57	19.27	17.41	16.57	12.42	12.12	17.09	17.83
15	24.10	21.87	22.22	20.64	18.46	20.02	17.51	12.83	14.08	15.33	18.71
16	21.15	26.84	19.57	21.15	18.32	18.62	17.68	14.36	10.72	13.88	18.23
17	18.75	23.52	19.39	19.08	16.21	18.12	14.29	12.07	6.34	6.48	15.63
18	21.81	19.24	16.04	17.96	15.72	14.11	12.50	11.21	6.40	9.30	14.43
19	14.86	21.37	19.42	18.77	17.81	16.19	15.21	8.41	4.51	8.44	14.50
20	17.32	19.28	15.03	15.35	16.01	16.34	18.95	11.75	4.24	6.20	14.05
Ave.	19.63	23.68	19.41	21.01	20.65	20.88	19.24	17.05	14.48	17.11	

Note: Water level 1 is adjacent to the sprinkler system. The distance between water levels was 2.5 ft (0.76 m). Averages of four replications.

Alfalfa Results in Vernal 1975

The dates and amounts of irrigation water applied for the salinized alfalfa plot study are shown in Table 36. Two replications were measured for irrigation applied.

The alfalfa dry matter yields are shown in Table 37. The data show no yield decrease due to either the variable water or salinity treatments. Lack of a yield decrease due to water level treatments could be a result of the high water table. Unlike the corn data, there was probably no yield decrease due to salinity treatment because the alfalfa roots were already established

TABLE 36. IRRIGATION APPLIED AT VERNAL, UTAH, ON THE ALFALFA PLOTS IN 1975

Date	Rep	Distance from sprinkler line - meters								
		0.38	2.21	4.04	5.87	7.70	9.52	11.35	13.18	15.01
					-- cm --					
7-3	A	5.6	7.0	6.4	5.7	5.6	4.2	2.2	0.5	0.6
	B	6.2	6.9	7.5	7.9	7.3	3.5	2.0	1.1	0.6
7-18	A	9.8	10.3	10.7	9.6	11.1	6.8	4.9	4.1	0
	B	9.8	13.6	10.7	8.8	6.9	5.4	5.7	3.1	4.4
8-11	A	13.0	12.0	12.4	10.0	7.6	5.3	3.5	1.6	0.7
	B	12.2	10.9	10.2	9.4	7.5	5.8	2.4	1.5	0
8-28	A	6.9	7.5	9.5	8.8	3.5	2.8	4.4	1.9	1.5
	B	6.2	6.1	5.0	4.6	4.6	3.0	1.8	1.1	0
Totals	A	35.2	37.0	39.0	34.2	27.9	19.2	14.9	8.1	2.7
	B	34.5	37.4	33.5	30.7	26.3	17.7	12.0	6.7	5.0
	Ave	34.9	37.2	36.3	32.5	27.1	18.5	13.5	7.4	3.9

when salt was applied. Some of the roots were undoubtedly functioning below the level where the salty water penetrated. A summary of dry matter yields by treatment are shown in Table 38.

Corn Results in Logan in 1975

The dates and amounts of water applied by irrigation in the 1975 corn studies at Logan are given in Table 39.

Table 40 shows the grain corn yields at Logan in 1975 as influenced by both water and salt level. The data show a general decrease in yield as the salt level increased. There was little indication of an interaction of salinity level and water level because the relative yield decrease from S1 to S6 was about the same for all water levels. There was a general decrease in yield as irrigation water applied decreased below about 12 inches (30 cm) (water treatment level 9). The corn dry matter yields in Table 41 show the same general trends as the dry matter yields.

TABLE 37. ALFALFA DRY MATTER YIELDS AS INFLUENCED BY SALINITY AND WATER LEVELS AT VERNAL, UTAH, 1975. SECOND CROP HARVESTED JULY 31, 1975.

Water level		Salinity level						
		S_1	S_2	S_3	S_4	S_5	S_6	Ave
		-- mt/ha --						
W1	Rep 1	6.8	4.6	4.6	6.0	5.6	7.0	5.8
W1	Rep 2	5.0	6.2	8.2	5.0	6.0	6.0	6.1
W1	Rep 3	6.4	5.2	7.0	4.6	6.8	3.2	5.5
W1	Rep 4	8.0	5.6	5.2	4.0	6.0	4.0	5.5
W1	Ave	6.6	5.4	6.3	4.9	6.1	5.1	5.7
W2	Rep 1	7.0	6.4	5.6	5.4	6.0	5.6	6.0
W2	Rep 2	8.0	6.2	6.0	5.4	5.8	6.8	6.4
W2	Rep 3	7.4	6.5	6.2	4.8	5.4	3.8	5.7
W2	Rep 4	8.2	4.1	6.4	4.6	7.2	4.9	5.9
W2	Ave	7.7	5.8	6.1	5.1	6.1	5.4	6.0
W3	Rep 1	6.2	6.4	4.6	6.6	4.8	7.4	6.0
W3	Rep 2	5.4	5.6	5.6	5.2	4.6	7.4	5.6
W3	Rep 3	7.0	5.4	6.6	4.6	4.2	5.0	5.5
W3	Rep 4	8.0	5.6	6.8	5.6	7.2	5.0	6.4
W3	Ave	6.7	5.8	5.9	5.5	5.2	6.2	5.9
W4	Rep 1	6.9	7.0	5.4	6.4	5.8	7.2	6.5
W4	Rep 2	7.2	4.6	5.4	5.2	4.8	5.0	5.4
W4	Rep 3	6.4	5.2	6.2	6.4	8.8	5.0	6.3
W4	Rep 4	8.4	4.8	6.0	5.0	5.6	4.5	5.7
W4	Ave	7.2	5.4	5.8	5.8	6.3	5.4	6.0
W5	Rep 1	6.6	7.0	8.4	8.6	8.2	6.0	7.5
W5	Rep 2	4.0	5.0	4.4	6.4	4.0	6.2	5.0
W5	Rep 3	4.8	6.2	5.8	7.4	5.6	5.2	5.8
W5	Rep 4	8.0	5.4	7.8	5.2	6.0	4.6	6.2
W5	Ave	5.9	5.9	6.6	6.4	6.0	5.5	6.1
All	Ave	6.8	5.7	6.1	5.5	5.9	5.5	5.9

TABLE 37. CONTINUED. THIRD CROP OF ALFALFA HARVESTED SEPTEMBER 12, 1972

Water level		Salinity Level S_1	S_2	S_3	S_4	S_5	S_6	Ave.
					-- mt/ha --			
W1	Rep 1	3.0	2.7	2.7	2.7	3.8	3.0	3.0
W1	Rep 2	2.7	2.5	2.5	3.0	2.9	2.9	2.8
W1	Rep 3	2.5	3.6	2.3	3.2	3.2	2.3	2.9
W1	Rep 4	2.7	3.4	2.2	3.1	2.1	2.3	2.6
W1	Ave	2.7	3.1	2.4	3.0	3.0	2.6	2.8
W2	Rep 1	3.4	2.5	3.4	2.9	3.3	3.8	3.2
W2	Rep 2	2.5	2.9	3.4	3.2	2.7	3.4	3.0
W2	Rep 3	2.9	3.2	2.6	3.6	3.1	2.0	2.9
W2	Rep 4	2.5	3.6	2.4	3.2	2.3	2.9	2.8
W2	Ave	2.8	3.1	3.0	3.2	2.9	3.0	3.0
W3	Rep 1	3.1	2.8	2.6	3.4	3.1	3.0	3.0
W3	Rep 2	3.3	2.8	3.7	3.0	2.8	3.5	3.2
W3	Rep 3	1.8	4.3	3.0	3.1	3.4	1.8	2.9
W3	Rep 4	2.9	3.3	2.4	3.7	2.0	2.2	2.8
W3	Ave	2.8	3.3	2.9	3.3	2.8	2.6	3.0
W4	Rep 1	2.8	2.8	2.6	2.8	2.8	3.0	2.8
W4	Rep 2	3.2	3.0	2.5	3.0	2.8	3.4	3.0
W4	Rep 3	2.6	3.1	2.8	2.8	3.0	1.9	2.7
W4	Rep 4	3.0	3.4	1.7	4.0	2.5	2.1	2.8
W4	Ave	2.9	3.1	2.4	3.2	2.8	2.6	2.8
W5	Rep 1	2.0	2.2	2.6	2.6	3.0	2.6	2.5
W5	Rep 2	2.0	2.6	3.2	2.4	2.8	2.8	2.8
W5	Rep 3	1.8	2.2	2.2	2.4	2.6	1.8	2.2
W5	Rep 4	2.0	3.4	1.4	3.4	2.0	1.8	2.3
W5	Ave	2.2	2.6	2.4	2.7	2.6	2.2	2.5
All	Ave	2.7	3.0	2.6	3.1	2.8	2.6	2.8

TABLE 38. SUMMARY OF ALFALFA DRY MATTER YIELDS FOR TWO HARVESTS AS AFFECTED BY SALT AND WATER TREATMENTS (VERNAL, 1975)

Water	Level	Salinity Level							Distance from Sprinkler line
		S_1	S_2	S_3	S_4	S_5	S_6	Ave	
		-- mt/ha --							
W1	2nd	6.6	5.4	6.3	4.9	6.1	5.1	5.7	
	3rd	2.7	3.1	2.4	3.0	3.0	2.6	2.8	
	Sum	9.3	8.5	8.7	7.9	9.1	7.7	8.5	0 to 3.0 m
W2	2nd	7.7	5.8	6.1	5.1	6.1	5.4	6.0	
	3rd	2.8	3.1	3.0	3.2	2.9	3.0	3.0	
	Sum	10.5	8.9	9.1	8.3	9.0	8.4	9.0	3.0 to 6.1 m
W3	2nd	6.7	5.8	5.9	5.5	5.2	6.2	5.9	
	3rd	2.8	3.3	2.9	3.3	2.8	2.6	3.0	
	Sum	9.5	9.1	8.8	8.8	8.0	8.8	8.9	6.1 to 9.1 m
W4	2nd	7.2	5.4	5.8	5.8	6.3	5.4	6.0	
	3rd	2.9	3.1	2.4	3.2	2.8	2.6	2.8	
	Sum	10.1	8.5	8.2	9.0	9.1	8.0	8.8	9.1 to 12.2 m
W5	2nd	5.9	5.9	6.6	6.4	6.0	5.5	6.1	
	3rd	2.2	2.6	2.4	2.7	2.6	2.2	2.5	
	Sum	8.1	8.5	9.0	9.1	8.6	7.7	8.6	12.2 to 15.2 m
All	2nd	6.8	5.7	6.1	5.5	5.9	5.5	5.9	
	3rd	2.7	3.0	2.6	3.1	2.8	2.6	2.8	
	Sum	9.5	8.7	8.7	8.6	8.7	8.1	8.7	

TABLE 39. IRRIGATION APPLIED AT VARIOUS DATES AND DISTANCES FROM THE SPRINKLER LINE IN LOGAN IN 1975.

Date	Rep	Distance from the sprinkler line-meters				
		1.5	4.6	7.6	10.6	13.7
				- cm -		
7-2	A	4.4	3.9	2.8	1.8	0.4
	B	4.5	3.9	2.9	2.0	0.9
7-9	A	4.2	3.8	2.4	1.6	0.4
	B	3.6	4.3	3.4	2.6	1.0
7-16	A	4.6	3.9	3.2	2.2	1.0
	B	4.5	3.9	2.5	1.4	0.8
7-22	A	2.5	2.3	1.9	1.4	0.4
	B	2.6	2.5	2.0	1.4	0.6
7-29	A	3.6	3.6	2.4	1.9	0.1
	B	3.9	3.7	3.7	0.8	0.1
8-6	A	2.2	2.1	1.9	1.0	0.4
	B	2.7	2.4	2.2	1.7	0.6
8-12	A	3.0	3.0	2.6	1.9	1.2
	B	3.4	3.2	2.9	2.1	1.2
8-18	A	2.7	2.9	2.3	1.2	0.4
	B	3.6	3.2	3.0	1.9	0.9
8-25	A	2.5	2.6	2.1	1.4	0.6
	B	3.3	3.1	2.8	1.8	0.7
9-4	A	2.3	2.3	1.8	1.4	0.7
	B	2.8	2.8	2.3	1.2	0.3
Total		33.4	31.6	25.5	16.4	6.3

TABLE 40. CORN GRAIN YIELDS AT LOGAN IN 1975 AS INFLUENCED BY SALINITY AND WATER LEVEL, AVERAGE OF 2 REPLICATES

Water Level	D_m^*	Salinity Level S1	S2	S3	S4	S5	S6	Ave
		- mt/ha -						
1	.38	7.4	7.3	6.2	7.5	6.5	4.2	6.4
2	1.14	7.1	6.8	6.5	6.4	5.9	3.8	5.8
3	1.9	7.3	7.1	7.6	6.5	6.2	4.2	6.5
4	2.17	7.6	7.7	7.1	6.6	4.9	3.3	6.2
5	3.4	7.9	6.2	7.0	6.5	4.7	3.3	5.9
6	4.2	8.6	8.4	7.2	7.5	5.9	4.2	6.9
7	4.9	8.6	7.5	8.3	7.5	6.2	4.6	7.1
8	5.7	7.1	6.4	7.3	6.2	5.1	3.2	5.9
9	6.5	8.3	8.3	7.2	7.3	5.1	5.2	6.9
10	7.2	7.1	5.4	5.3	5.9	3.3	3.4	5.0
11	8.0	6.1	6.2	6.0	5.6	3.1	2.9	4.9
12	8.7	8.0	7.3	7.2	6.0	8.0	4.4	5.9
13	9.5	8.1	6.8	5.4	4.1	2.4	3.0	4.9
14	10.3	7.4	6.0	5.7	7.0	5.0	3.3	5.7
15	11.0	7.8	7.5	6.8	6.4	4.7	2.7	6.0
16	11.8	5.7	4.5	5.2	4.0	2.7	2.3	4.0
17	12.5	6.2	6.5	5.6	5.0	3.5	2.7	4.9
18	12.3	6.1	5.8	5.5	3.5	3.2	2.6	4.4
19	14.1	5.3	4.6	3.8	3.0	2.1	2.0	3.4
Ave		7.1	6.5	6.2	5.7	4.3	3.4	

D_m^* = distance in meters from the sprinkler line

1 meter = 3.28 feet

TABLE 41. CORN DRY MATTER YIELDS AT LOGAN IN 1975 AS INFLUENCED BY SALINITY AND WATER LEVEL, AVERAGE OF TWO REPLICATES

Water Level	D_m*	Salinity Level S1	S2	S3	S4	S5	S6	Ave
					- mt/ha -			
1	.38	15.5	16.3	14.8	14.8	13.8	10.5	14.1
2	1.14	16.4	15.8	15.7	14.3	13.2	9.3	14.1
3	1.9	15.8	15.8	14.7	13.9	12.9	9.8	13.8
4	2.17	16.0	17.3	15.2	13.7	11.1	8.5	13.6
5	3.4	15.7	12.9	14.7	13.6	11.6	8.4	12.8
6	4.2	17.1	18.3	15.0	15.8	13.4	9.9	14.9
7	4.9	17.0	17.0	16.8	16.1	13.4	10.9	15.2
8	5.7	13.2	13.2	15.8	12.9	11.5	8.3	12.5
9	6.5	16.6	17.7	15.7	14.6	11.7	11.6	14.6
10	7.2	13.9	11.6	11.5	12.0	8.3	7.8	10.8
11	8.0	12.3	11.8	12.1	12.1	7.8	7.1	10.5
12	8.7	14.6	15.0	14.7	11.9	8.6	9.5	12.3
13	9.5	15.0	13.7	10.9	8.8	6.8	7.3	10.4
14	10.3	12.8	12.1	11.0	12.2	10.0	8.0	11.0
15	11.0	14.7	14.2	11.7	10.6	9.9	7.1	11.3
16	11.8	10.9	9.5	10.0	8.4	6.7	6.0	8.5
17	12.5	11.4	13.2	11.1	9.8	8.1	6.7	10.0
18	12.3	11.9	11.8	10.5	7.8	7.2	6.2	9.2
19	14.1	10.9	9.1	7.9	6.7	5.3	5.2	7.5
Ave		14.1	13.8	13.0	11.8	10.1	8.3	11.8

D_m* = distance in meters from the sprinkler line

1 meter = 3.28 feet

The corn yield data in Logan allowed more reliable estimates of response to evapotranspiration to be made than the data at Vernal because there was no flow up from a water table. Evapotranspiration estimates were made (assuming there was no drainage or upward flow) by summing irrigation, rain, and soil water depletion. Drainage was estimated to be near zero from lysimeter measurements. These data are shown in Figures 38 and 39. The data indicate that yields are strongly related to evapotranspiration although there is considerable scatter in the data. The data in the figures indicate that yields from plots treated with different concentrations of saline water fit in with yields from plots treated with different concentrations of saline water fit in with yields from plots irrigated with the best quality water. The yields of the two S1 check treatments, one irrigated initially with canal water in the spring (the same as the other salinity treatments), and one not irrigated in the spring almost bracket the data. Since there is no reason to expect yield differences in the two check treatments (S1), the differences must be due to unmeasured variation. Thus it is concluded that the effect of different levels of salinity on yield can be explained as an effect of salinity on evapotranspiration. The apparent effect of salinity on evapotranspiration is reflected in soil water depletion, since irrigation and rain are the same regardless of the soil salinity condition. The effect of a high soil salinity is to decrease the water availability in the soil and therefore increase the soil water content at any given water potential.

The influence of salinity level on water depletions is shown in Table 42, and was to generally decrease the soil water depletion as the salinity level increased. Depletion increased as the water applied decreased (increasing water level treatment numbers). These results tend to show that the effect of salinity is to reduce water availability for evapotranspiration and therefore crop yields are reduced.

TABLE 42. SOIL WATER DEPLETION AS INFLUENCED BY WATER AND SALINITY LEVEL AT LOGAN IN 1975

Water Level	Salinity Level S1	S2	S3	S4	S5	S6	Ave
				cm			
3	13.2	12.7	10.8	6.2	0.6	—	8.7
10	14.7	10.4	15.1	12.0	2.8	4.8	11.0
19	16.8	10.4	12.1	16.3	11.0	--	13.3
Ave	14.9	11.2	12.7	11.5	4.8	4.8	

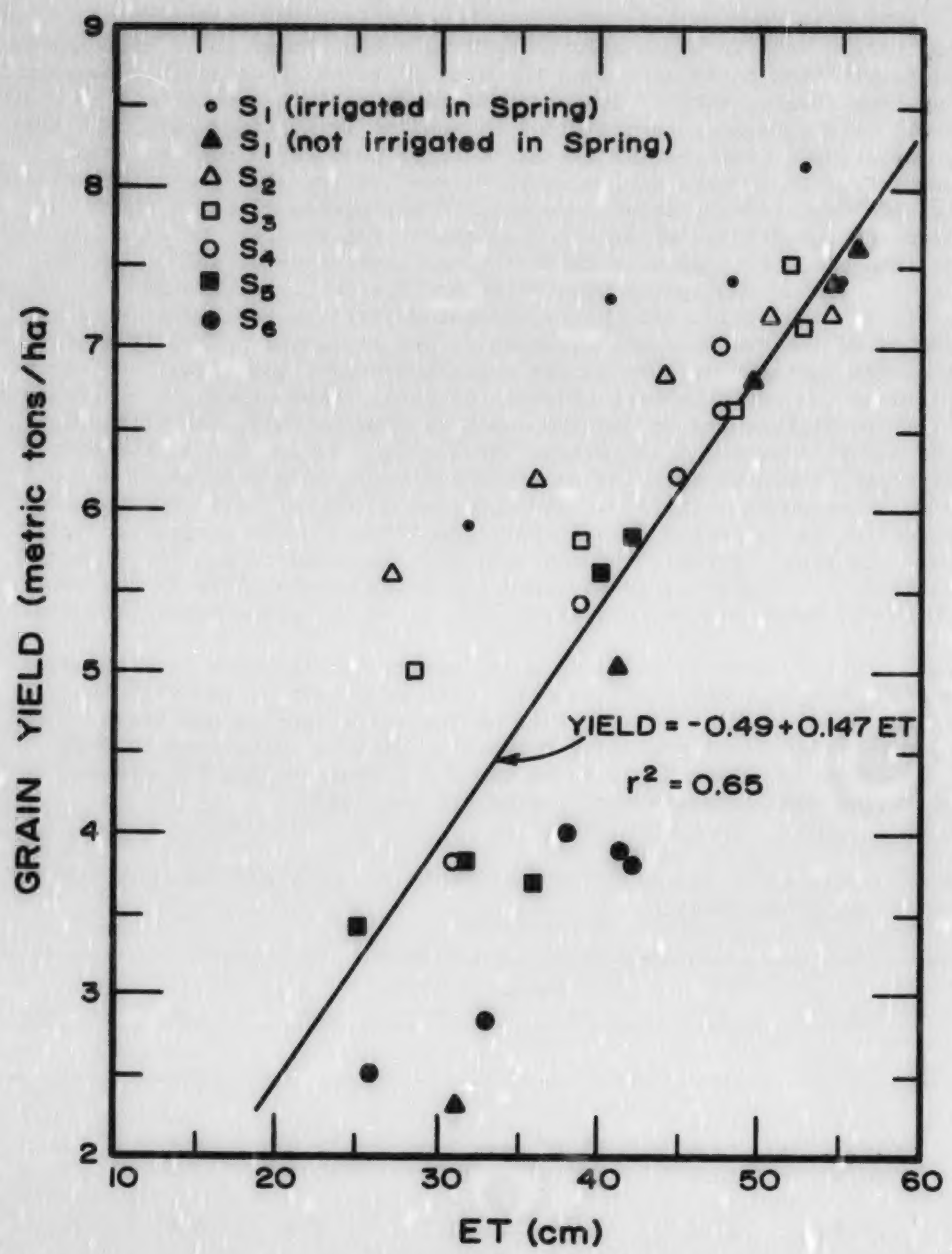


Figure 38. 1975 corn grain yield at Logan related to evapotranspiration.

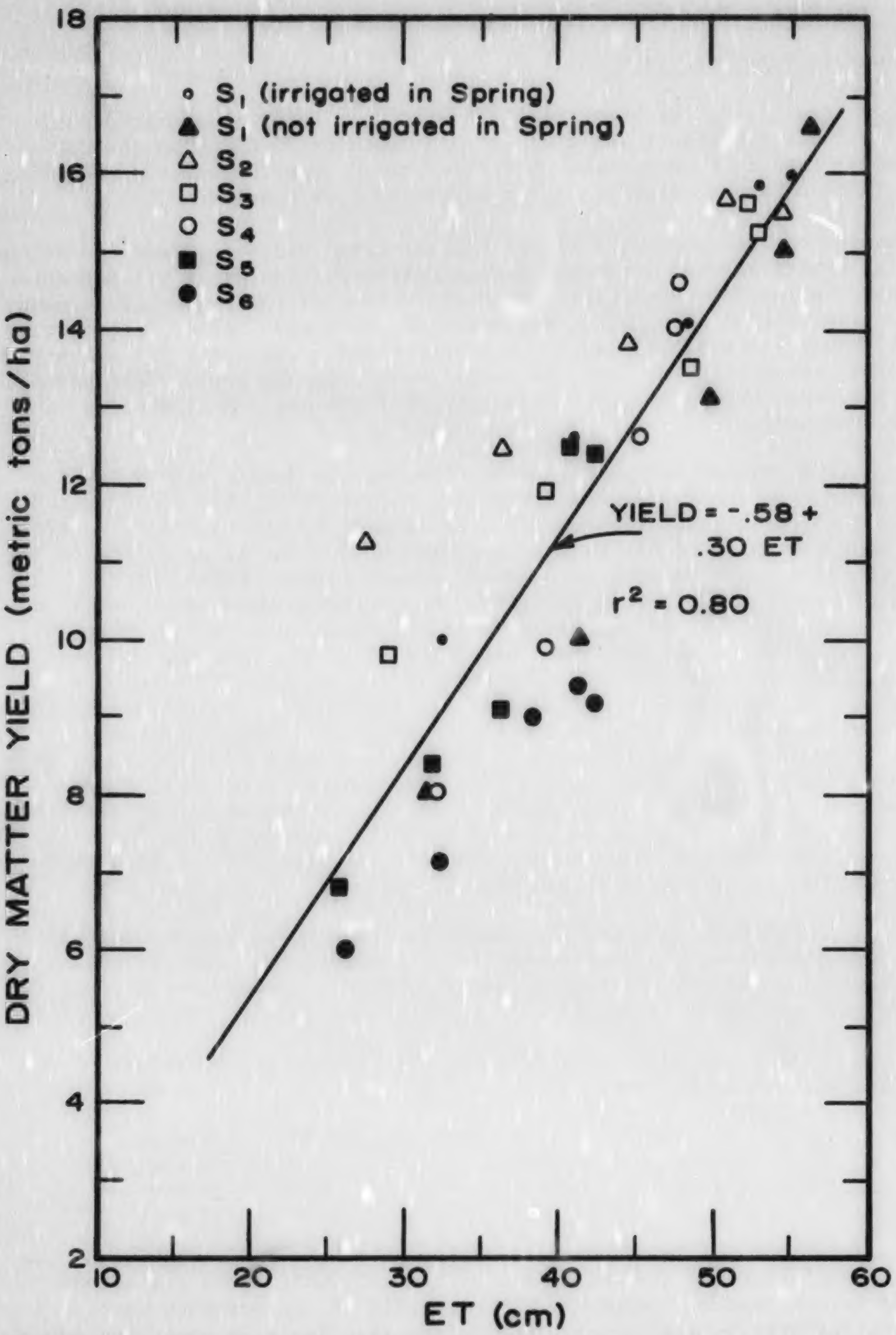


Figure 39. 1975 corn dry matter yield at Logan related to evapotranspiration.

TESTS OF THE SOURCE-SINK MODEL UNDER LABORATORY CONDITIONS

Experiments in Saturated Flow

Laboratory trial 1 - A leaching trial was conducted using a saturated soil in small columns. The soil was taken from a depth of 30-60 cm on the USU experimental farm in Vernal. The objective was to test the computer model that included a "source-sink" term for saturated flow conditions.

Two segmented soil columns were filled and saturated under the same conditions. A leaching experiment was performed on one column and the other was segmented after only the initial saturation. In each section of the segmented columns, the EC of the saturation solution extracted was measured. After first drying the soil, the EC of a 1:5 extraction was determined. The first 1:5 extraction more nearly represented the total salinity present in the soil. Salt balance data from several trials indicated that the EC (1:5) was a good measure of the total salinity.

Leaching of the columns was performed by flooding the sample with a constant head of water. During the leaching process, the volume of the effluent and its electrical conductivity, the EC(4P), and the EC by the salinity sensors located near the walls of the column, were measured. The setup of the experiment is illustrated in Figure 40. The measurements taken during leaching treatment are shown in Table 43. Measurements were taken until the rate of change of the EC of the effluent solution was very small. Then the soil was leached for a few more days until the EC of the influent and the EC of the effluent was the same. This equilibrium is an indication of a complete dissolution of salts in the soil and a complete displacement of the initial soil solution. In the next step the EC_{ir} was changed and measurements of the volume and the EC of the effluent were taken in order to compute the apparent diffusion coefficient, D_p. D_p was computed and found to be 16.98 cm^2/hr. (For the detailed data used in the computation of D_p see Table 43). The interstitial velocity, U, was 5.07 cm/hr. Assuming that $D = \lambda|U|$ is valid, the λ used for the computations was 3.35 cm. Determinations were made for each of the five segments of the column.

For the numerical solution using the model, the column was divided into 10.5 sections and the column was represented by 12 grid points. The 12th point was imaginary, out of the physical boundary, and was assumed always equal to grid point no. 11. (See Figure 41).

If a, b, c, d and e represent data from the five segments, the values of the grid points will be as follows:

1 = A
2 = A
3 = (2.23A + .15B)/2.38
4 = B
5 = (2.27B + .11C)/2.38
6 = C
7 = C
8 = D
9 = D
10 = E
11 = E
12 = 11

Values used for the initial conditions of the EC of the soil solution in the model were the values of the extraction of the soil water from the second unleached column that was segmented. The results of the segments were related to the grid points as explained before (see Table 44). Values for

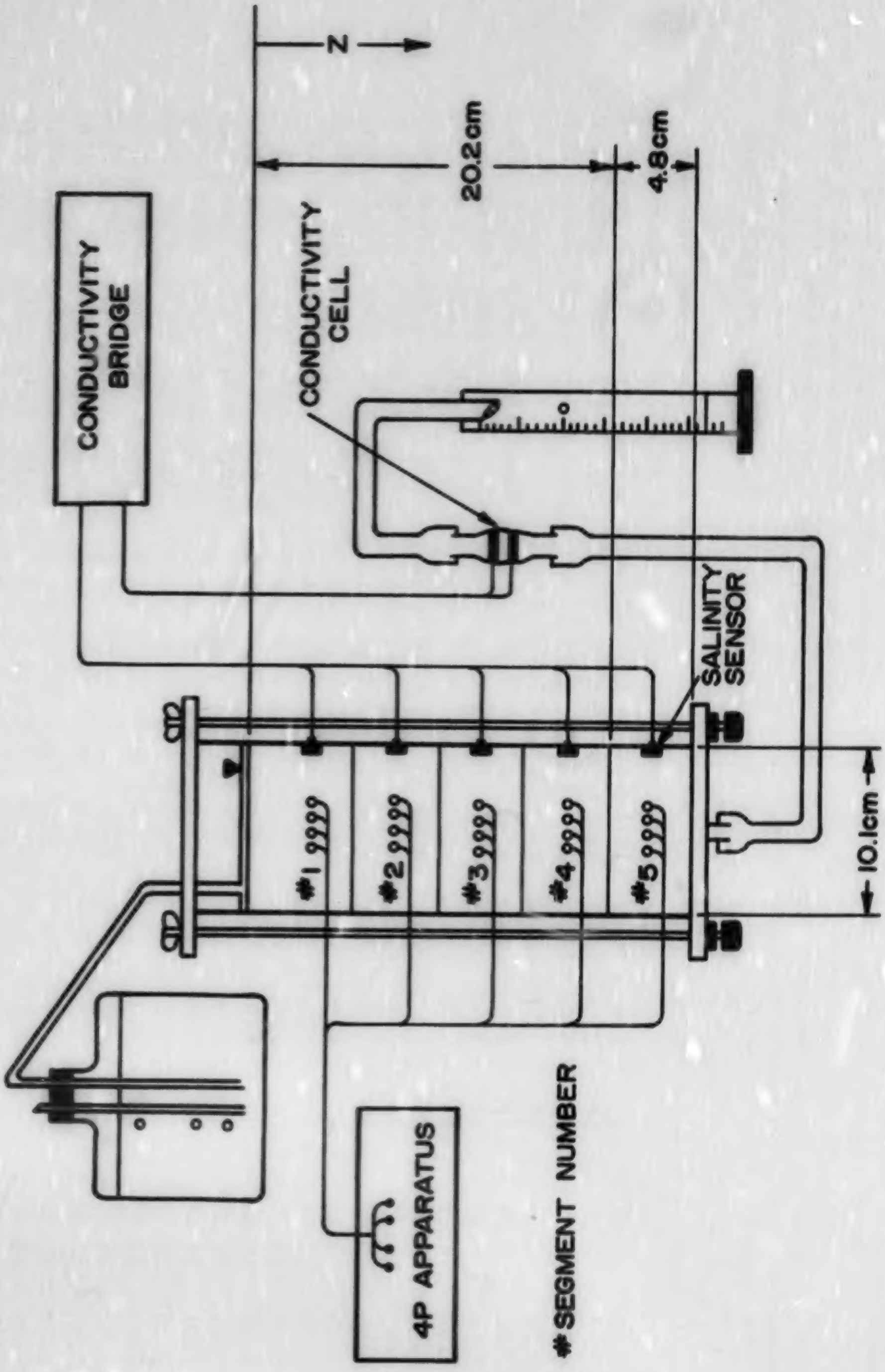

CONDUCTIVITY BRIDGE
CONDUCTIVITY CELL
Z
20.2cm
4.8cm
SALINITY SENSOR
10.1cm
#1
#2
#3
#4
#5
4P APPARATUS
# SEGMENT NUMBER

Figure 40. The setup of laboratory leaching experiments 1 and 2.

TABLE 43. RESULTS OF LEACHING TRIAL 1.

General Data:

Bulk density = 1.32 g/cm^3
Water fraction = .506
Length of soil column = 25 cm
Area of cross section = 80.1 cm^2

1 pore volume = 10.3 cm^3
Average Darcian velocity = 2.16 cm/h
Average interstitial velocity = 4.27 cm/h
EC of the influent = 2850 µmho

Σt (min)	Σt* (h)	Def** (cm)	Pore volume	ECef (µmho)	EC(4P) mmho 1(top)	2	3	4	5	EC salinity sensors (µmho) 1	2	3	4	5
0	0	0			16.0	14.3	15.5	18.5	17.5	4700	4780	4570	7850	5890
25	.34	.75	.06	10700	15.2	14.0	14.7	17.8	17.0	4770	4790	4480	5140	5770
66	.92	2.00	.16	9750	12.2	14.7	14.3	17.0	16.0	4631	4950	4480	4930	5590
108	1.50	3.25	.26	8800	10.0	13.5	14.5	16.0	15.0	4050	4920	4620	7400	5370
150	2.08	4.49	.36	8300	9.4	11.3	13.5	15.2	14.5					
191	2.60	5.74	.45	8200	9.3	11.0	12.7	15.0	14.3	3320	4290	4310	6930	4960
232	3.24	6.99	.55	8100	9.0	10.6	11.7	14.5	14.2	3110	4060	4070	6400	4840
273	3.81	8.24	.65	7550	8.9	10.2	11.3	13.5	13.4	2960	3860	3840	6000	4600
314	4.39	9.49	.75	7200	8.7	10.1	11.2	12.8	12.7	2830	3710	3680	5610	4350
354	4.97	10.75	.85	7050	8.7	10.0	11.0	12.5	12.0	2760	3600	3510	5350	4130
394	5.55	11.98	.95	6800	8.6	10.0	10.8	12.2	11.8	2680	3520	3395	5115	3970
434	6.13	13.23	1.05	6500	8.4	9.7	10.6	12.1	11.5	2620	3410	3291	5036	3800
473	6.70	14.48	1.14	6350	8.4	9.6	10.5	12.0	11.5	2580	3350	3217	4830	3730
513	7.28	15.73	1.24	6200	8.3	9.5	10.4	11.9	11.5	2540	3300	3150	4720	3660
553	7.86	16.98	1.34	6100	8.3,	9.4	10.3	11.8	11.4	2500	3260	3100	4560	3610
591	8.44	18.23	1.44	6000	8.2	9.2	10.0	11.7	11.3	2480	3190	3020	4460	3560
629	9.01	19.48	1.54	5850	8.2	9.1	10.0	11.6	11.3	2470	3180	2990	4460	3520
667	9.59	20.72	1.64	5750	8.2	9.0	9.8	11.6	11.2	2450	3160	2950	4380	3510
767	11.04	23.85	1.88	5440	8.0	8.9	9.5	11.3	11.1	2380	3090	2850	4110	3410
861	12.48	26.97	2.13	5200	7.9	8.6	9.2	11.0	10.8	2350	3050	2770	3880	3300
959	13.93	30.09	2.38	5120	7.9	8.6	9.1	10.8	10.6	2320	3020	2700	3510	3180
1141	16.82	36.33	2.87	4900	7.9	8.5	8.9	10.2	10.1	2280	3000	2590	3120	2870
1515	22.60	48.81	3.86	4560	7.9	8.4	8.8	9.4	9.4	2270	3000	2510	2800	2520
1705	25.49	55.06	4.35	4240	7.9	8.4	8.8	9.3	9.2	2270	3010	2490	2560	2450
1891	28.38	61.30	4.84	4080	7.9	8.4	8.8	9.1	9.0	2250	3020	2470	2510	2390

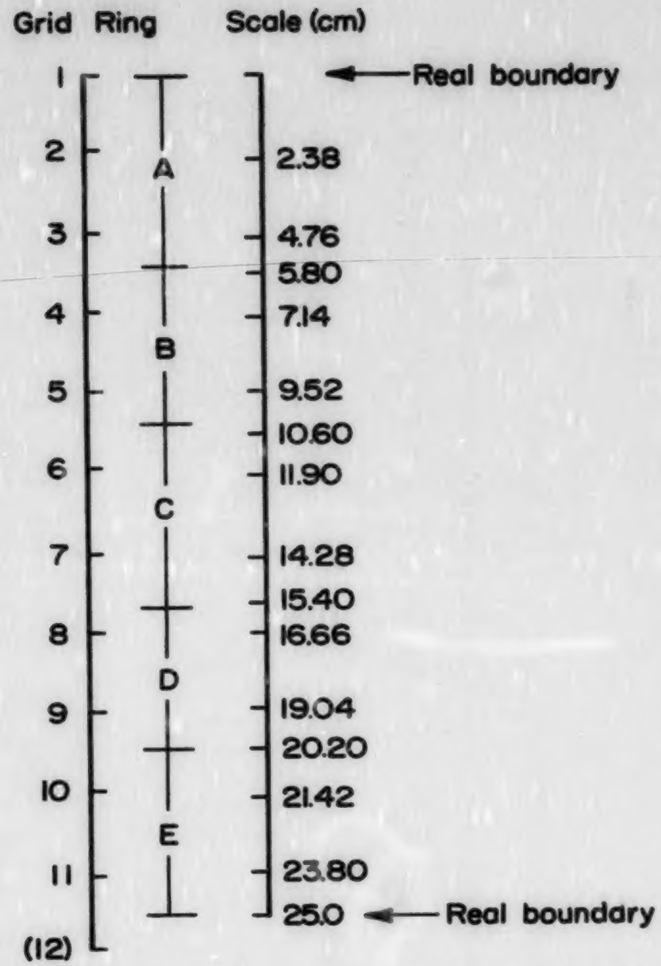
TABLE 43. RESULTS OF LEACHING, TRIAL 1 (CONTINUED)

Σt (min)	Σt* (h)	Def** (cm)	Pore volume	ECef (μmho)	EC(4P) mmho 1(top)	2	3	4	5	EC Salinity sensors (μmho) 1	2	3	4	5
2060	31.04	67.04	5.30	4000	7.9	8.4	8.8	9.0	8.9	2240	3010	2450	2480	2360
2422	36.82	79.53	6.29	3640	8.0	8.4	8.8	8.9	8.7	2240	3038	2450	2300	2340
2945	45.17	97.56	7.71	3420	8.0	8.4	8.8	8.9	8.6	2240	3070	2500	1850	2340
3400	54.17	117.00	9.25	3210	8.0	8.4	8.8	8.9	8.6	2270	3130	2470	1990	2370
3900	64.00	138.25	10.93	3050	8.0	8.4	8.8	8.9	8.6	2210	3090	2470	1910	2340
4450	74.13	160.11	12.65	2980	8.0	8.4	8.8	8.9	8.6	2220	3100	2480	1960	2370

The reference column Segment:	1	2	3	4	5
EC of 1:5 extraction (μmho)	980	1310	1420	1570	1500
EC of immediate extraction (μmho)	6500	6000	7500	8600	9600

*Time corrected for constant velocity

** Depth of effluent


Grid Ring
Scale (cm)
Real boundary
1
2
3
4
5
6
7
8
9
10
11
(12)
A
B
C
D
E
2.38
4.76
5.80
7.14
9.52
10.60
11.90
14.28
15.40
16.66
19.04
20.20
21.42
23.80
25.0
Real boundary

If A, B, C, D and E represent data from the five segments, the values of the grid points will be as follows:

1 = A
2 = A
3 = (2.23A + .15B)/2.38
4 = B
5 = (2.27B + .11C)/2.38
6 = C
7 = C
8 = D
9 = D
10 = E
11 = E
12 = 11

Figure 41. The location of the grid points relative to the experimental segments.

TABLE 44. THE INITIAL SALINITY CONDITIONS USED IN TRIAL 1

Grid point No.	EC solution (mmho/cm)	Solid salts (mmho/cm)
1	6.50	3.18
2	6.50	3.18
3	6.47	3.33
4	6.00	5.61
5	6.07	5.61
6	7.50	5.58
7	7.50	5.58
8	8.60	6.01
9	8.60	6.01
10	9.60	5.04
11	9.60	5.04

the initial solid salts in the sample were obtained by subtracting the salts in the saturated solution from the salts found in the 1:5 extraction. The solid salts were expressed as a ratio between the salts in a unit volume of soil to the water fraction in the soil, in order to simplify additional computations. For example: EC solution = 6.50 mmho/cm. EC (1:5) = 0.98 mmho/cm. $\rho_b = 1.32\ g/cm^3$. $\theta_v = 0.506$.

$$\text{Solid salts} = \frac{0.98 \times 5 \times 1.32 - 6.5 \times 0.506}{0.506} = 6.28 \text{ mmho/cm.}$$

The computation of C_i^j was done by a numerical approximation. For the saturated flow equation [10] was reduced to:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial z^2} - U\frac{\partial C}{\partial z} + K(R - C) \qquad [18]$$

K = K for S > 0
K = 0 for S = 0

The boundary conditions were as follows: $C(0, t) = C_{ir}$ top boundary. C_{ir} is the concentration of the influent water $\left(\frac{\partial C}{\partial z}\right)_{z=Z} = 0$ bottom boundary.

For equal space increments equation [18] was approximated by:

$$C_{i-1}^{j+1} \times a + C_i^{j+1} \times b + C_{i+1}^{j+1} \times c = d \qquad [19]$$

where $a = \left(\frac{D}{2\Delta_z{}^2} - \frac{D}{4\Delta z}\right)$, $b = \left(-\frac{1}{t} - \frac{D}{\Delta z^2}\right)$, $c = \left(\frac{D}{2\Delta z^2} - \frac{D}{4\Delta z}\right)$,

$$d = -\frac{1}{t} X C_i^j - \frac{D}{2\Delta z^2} (C_{i+1}^j - 2C_i^j + C_{i-1}^j) + \frac{U}{4\Delta az} (C_{i+1}^j - C_{i-1}^j) - K(R - C_i^j)$$

$C_1^{j+1} = C_{ir}$.

The physical boundary is at $z_{N+\frac{1}{2}}$ at the bottom of the column. The second order approximation for $\left(\frac{\partial C}{\partial z}\right)_{N+\frac{1}{2}}$ was used $\frac{C_{N+1} - C_N}{z}$. The first equation in the linear set is: $C_2^{j+1} X b + C_3^{j+1} X c = d - C_{ir} X a$. The N-1 equation is: $C_{N-1}^{j+1} X a + CN^{j+1} X (b + c) = d$.

The parameter K was found by a "trial and error" procedure in which the criterion for fitness was $\sum_{j=1}^{n} | ECC_j - ECM_j | (T_j - T_{j-1})$ which is a sum of the weighted absolute deviations.

ECC is the computed EC of the effluent and ECM is the measured EC of the effluent, both at time "j."

The detailed program used to search for the optimal K and plot the measured and the computed results (using the chosen K) vs. time can be found in Appendix C.

The computed and the measured electrical conductivity of the effluent as a function of time is shown in Figure 42. By using the D that was computed for the column, it is possible to find a suitable K value for the model and simulate the measured data with reasonable accuracy. The biggest deviation of the computed data and the measured data was in the first stage of the leaching process. Comparing the measured results with those computed without a source term (K = 0 in Figure 42) demonstrates the improvement achieved by including a source term in the model. When no source term was used, the model results showed that the initial solution was completely displaced after about two pore volumes of effluent (12 hr) had passed through the column. For a zero source term, this would be the result expected.

Figure 43 compares the EC computed by the model and the EC(4P) measured by the calibrated four-probe method as a function of time for the five experimental column segments. Except for the measurements in the first ring, the EC measured and the EC computed by the model showed reasonable agreement.

Laboratory trial 2 - The objective of trial 2 was to determine whether the same order of magnitude of K would be obtained when the experiment was repeated with the same soil under different initial conditions.

The procedure was similar to that used in trial 1. Initial salinity conditions, which differed from those which existed in trial 1, were obtained by using for the prewetting treatment, solutions of different concentrations, and by wetting the columns in the upwards direction. The initial conditions were measured as in trial 1 and are shown in Table 45. The data from the

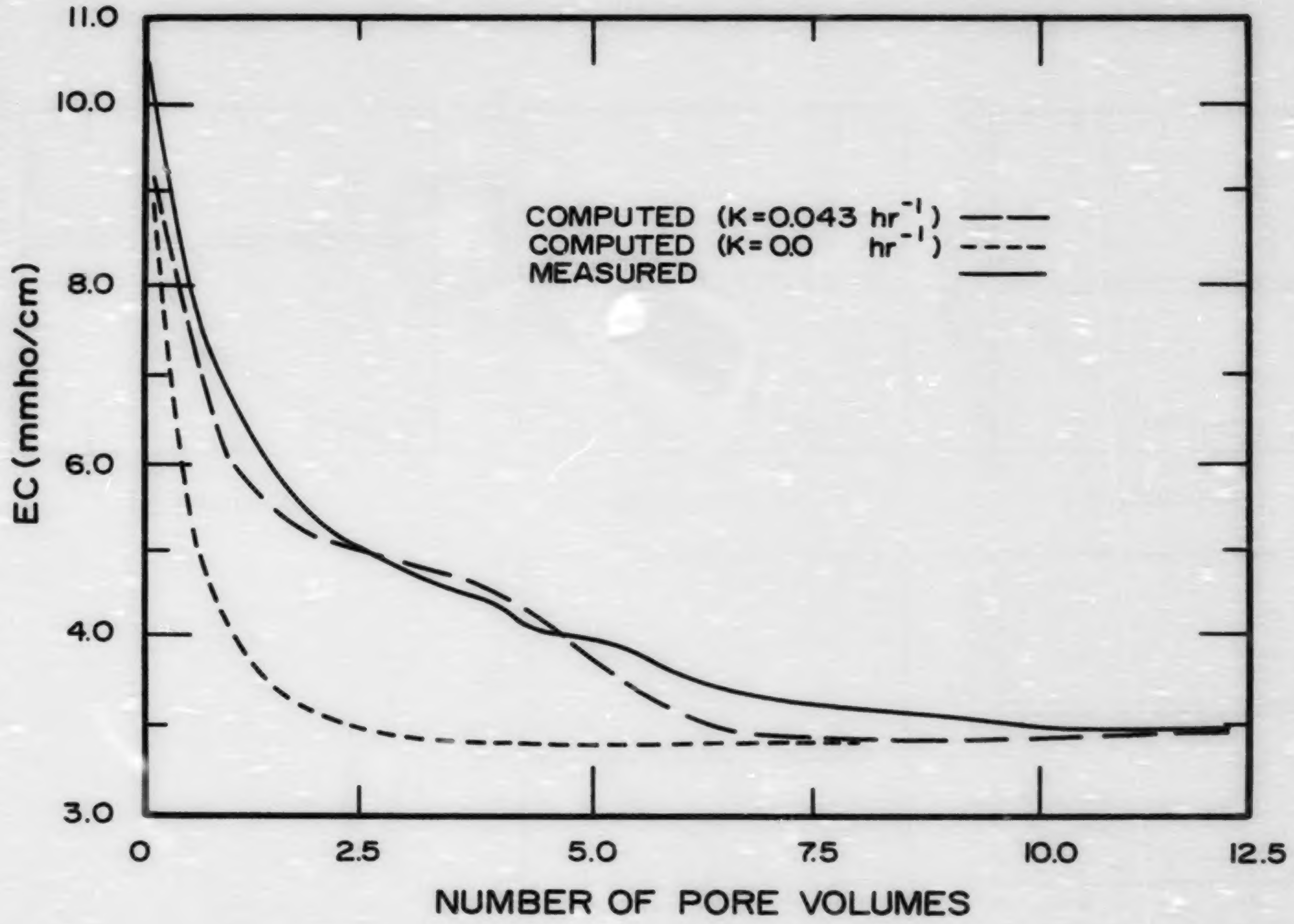


Figure 42. Computed and measured EC of the effluent vs time - Laboratory trial 1.

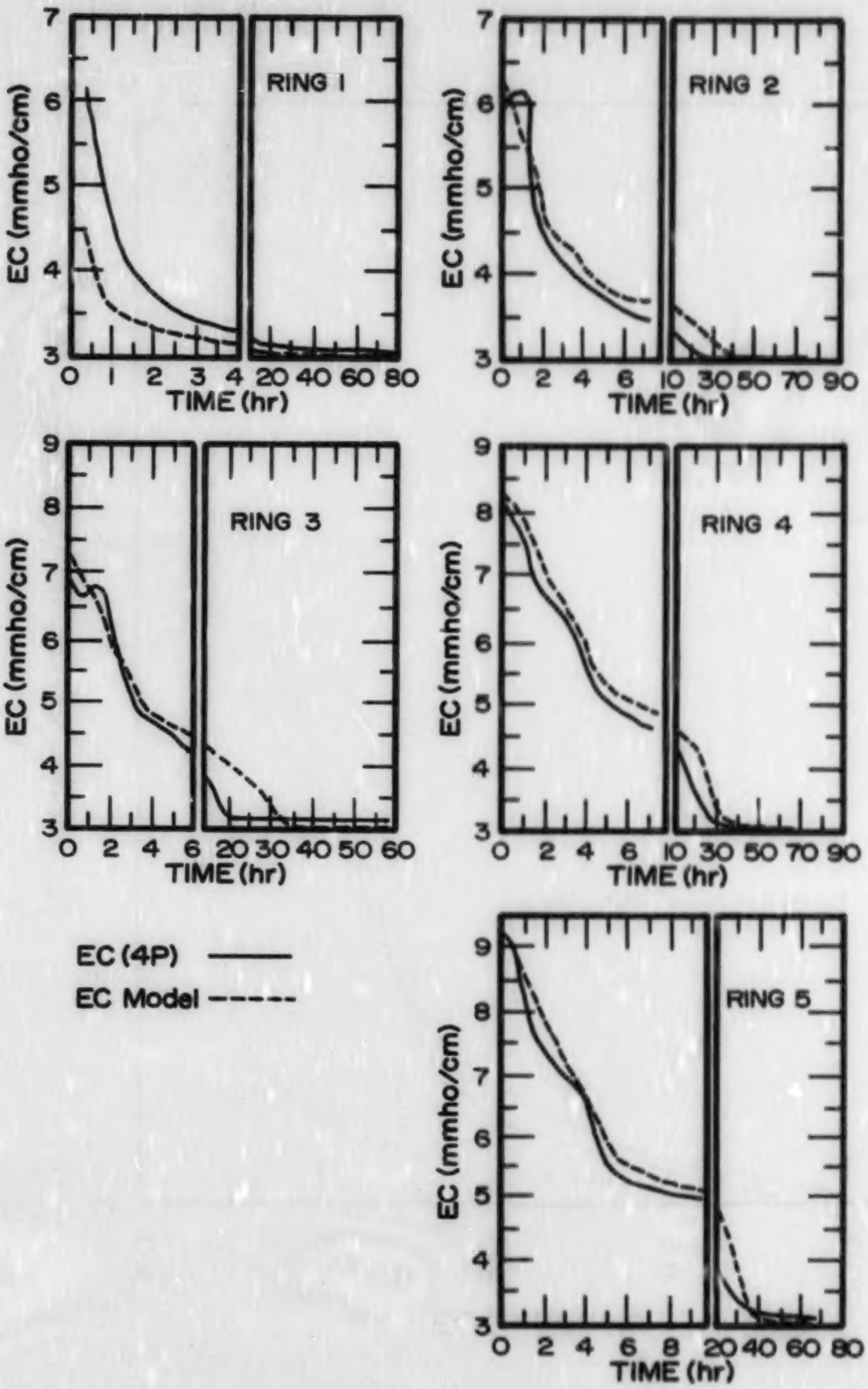


Figure 43. EC computed by the model and by the (4P) vs. time laboratory trial 1.

TABLE 45. THE INITIAL SALINITY CONDITIONS USED IN TRIAL 2

Grid point No.	EC solution (mmho/cm)	Solid salts (mmho/cm)
1	6.50	14.45
2	6.50	14.45
3	6.11	14.28
4	5.50	14.28
5	5.56	13.79
6	5.70	13.79
7	6.07	11.81
8	6.40	11.60
9	6.40	11.13
10	6.40	6.15
11	6.40	6.15

leaching treatment are shown in Table 46. D for the second trial was computed and found to be 15.47 cm^2/hr., λ was 3.89 cm (the detailed computation can be found in Appendix D).

Figure 44 shows the computed and measured EC of the effluent as a function of time and indicates that the model simulates the measured EC of the effluent with reasonable accuracy. However, the computed curve did not simulate the measured data very well in the initial stage of the leaching. The optimal K found was almost the same as the one found in trial 1.

A comparison between the EC of the soil solution computed by the model and that measured by the calibrated (4P) for the five experimental segments is illustrated in Figure 45. A good agreement between the two methods existed only in ring 4 and ring 5. Differences found in the upper three rings may have been caused by the method used for wetting the sample initially. In all of the rings, however, the EC(4P) shows the correct direction of the process.

Experiments in Unsaturated Soil

Laboratory trial 3 - The objective of this trial was to study the possibility of finding a "source-sink" term, as in the saturated flow experiments, to describe salt movement in unsaturated flow conditions.

Procedure - Air dry soil was packed in a column consisting of five rings (segments) as in trials 1 and 2. The supply of the influent was provided by a small adjustable pump which discharged the influent into a rotating

TABLE 46. RESULTS OF LEACHING EXPERIMENT NO. 2

General data:

Bulk density = 1.255 g/cm^3
Water fraction = 0.53
Length of soil column = 24 cm
Area of cross-section = 80.1 cm^2
One pore volume = 1019 cm^3
Average Darcian velocity = 2.68 cm/hr
Average interstitial velocity = 5.06 cm/hr
EC of the influent = 1920 μmho/cm

Δt min	Σt min	Σt* hr	Def cm	P	ECef mho/cm	EC(4P) (mmho/cm) 1 top	2	3	4	5
						18.3	14.2	14.0	17.5	15.1
10	10	.13	.33	.03	6600	18.3	14.3	14.0	17.5	15.1
10	20	.28	.75	.06	6600	16.9	15.0	14.3	16.5	14.5
18	38	.56	1.59	.12	6150	12.6	15.7	14.6	16.0	14.0
12	50	.76	2.05	.16	5850	11.5	14.9	14.9	16.0	13.5
15	65	1.02	2.75	.22	5650	10.8	13.0	15.2	16.4	13.5
9	74	1.16	3.12	.25	5600	10.6	12.8	15.3	16.9	13.5
11	85	1.33	3.57	.28	5650	10.1	12.0	14.9	17.3	13.8
15	100	1.57	4.22	.33	5800	9.7	11.7	13.5	17.7	14.3
15	115	1.81	4.84	.38	6100	9.3	11.3	12.7	17.1	14.7
22	137	2.17	5.82	.46	6300	9.0	11.0	11.8	14.6	14.2
11	148	2.33	6.24	.49	6600	8.8	10.8	11.6	14.3	13.7
17	165	2.62	7.03	.55	6500	8.6	10.5	11.5	13.5	12.5
15	180	2.87	7.69	.60	6300	8.5	10.2	11.4	13.2	12.3
13	193	3.14	8.43	.66	6400	8.4	10.0	11.3	13.0	12.0
16	209	3.38	9.05	.71	5850	8.4	9.8	11.2	12.8	11.6
11	220	3.54	9.49	.75	5750	8.3	9.5	11.1	12.7	11.5
15	235	3.78	10.14	.80	5650	8.2	9.4	11.0	12.5	11.3
15	250	4.00	10.74	.84	5500	8.1	9.1	10.9	12.4	11.2
15	265	4.26	11.42	.90	5100	8.1	9.0	10.8	12.4	11.1
25	290	4.68	12.56	.99	4800	8.0	8.6	10.6	12.1	10.8
35	325	5.19	14.43	1.09	4500	7.9	8.3	10.3	11.3	10.6
62	387	6.19	16.60	1.30	4300	7.7	7.7	9.6	11.5	10.2
28	415	6.94	18.60	1.46	4200	7.7	7.5	9.4	11.3	10.0
30	445	7.44	19.95	1.57	4000	7.7	7.3	9.1	11.0	9.8
43	488	8.09	21.68	1.70	3800	7.7	7.2	8.8	10.6	9.4
42	530	8.74	23.43	1.84	3800	7.7	7.1	8.5	10.3	9.2
90	620	10.19	27.33	2.15	3700	7.7	6.9	7.9	9.3	8.4
100	720	11.79	31.61	2.48	3700	7.6	6.8	7.5	8.7	7.1
110	830	13.59	36.44	2.86	3500	7.6	6.7	7.2	8.4	7.5
110	940	15.38	41.23	3.24	3500	7.6	6.7	7.0	8.1	7.2
235	1175	19.43	52.10	4.09	3300	7.6	6.7	6.8	7.8	6.9
235	1410	23.63	63.36	4.98	3200	7.7	6.7	6.8	7.6	6.8
105	1515	25.33	67.91	5.34	3200	7.8	6.7	6.8	7.6	6.8
127	1642	27.37	73.38	5.76	3100	7.8	6.7	6.8	7.6	6.8

The reference column Segment:	1	2	3	4	5
EC of the 1:5 extraction (μmho/cm)	1770	1650	1600	1520	1060
EC of the solution (μmho/cm)	6500	5500	5700	6400	6400

t* = time corrected for a constant velocity.

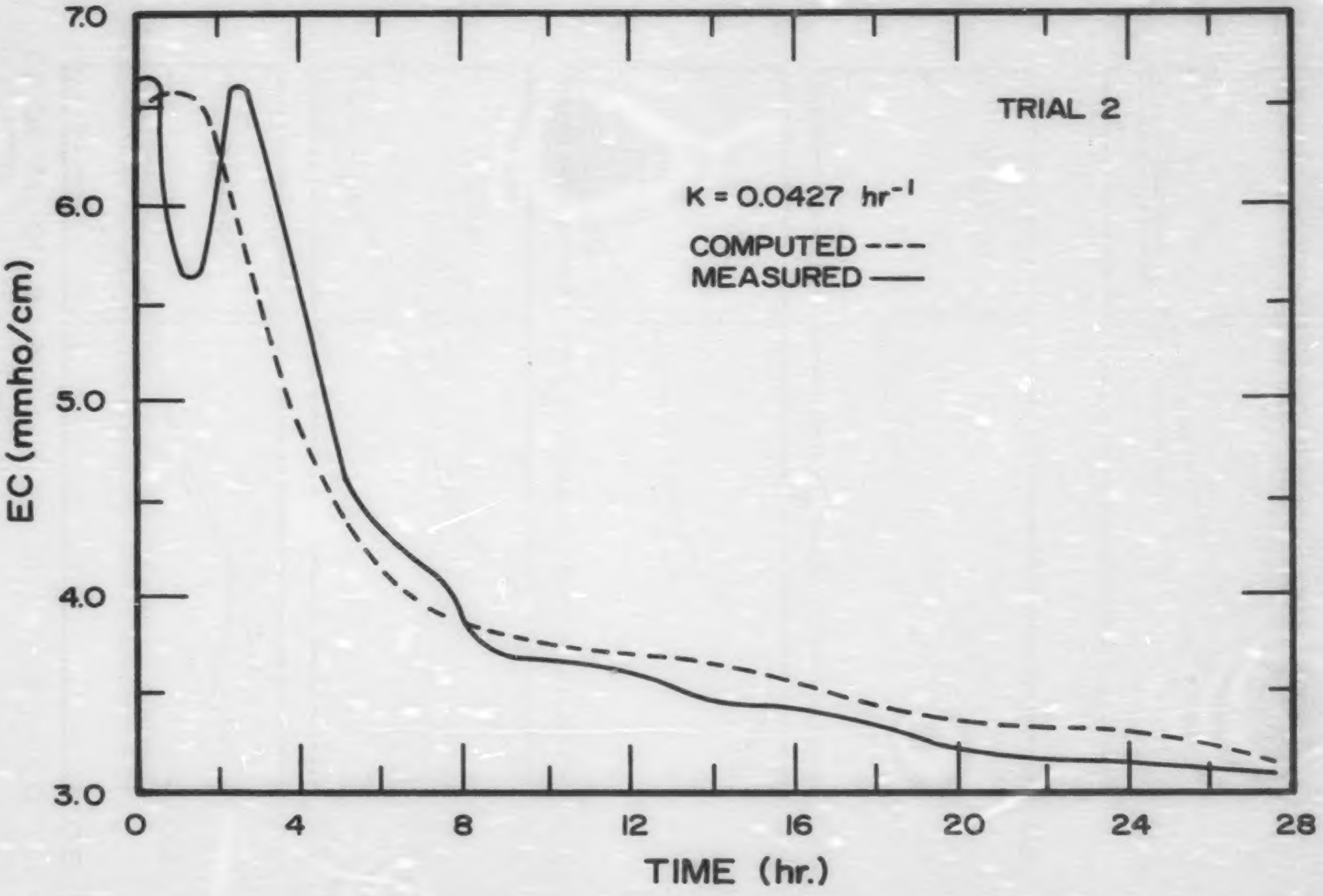


Figure 44. Computed and measured EC of the effluent vs. time.

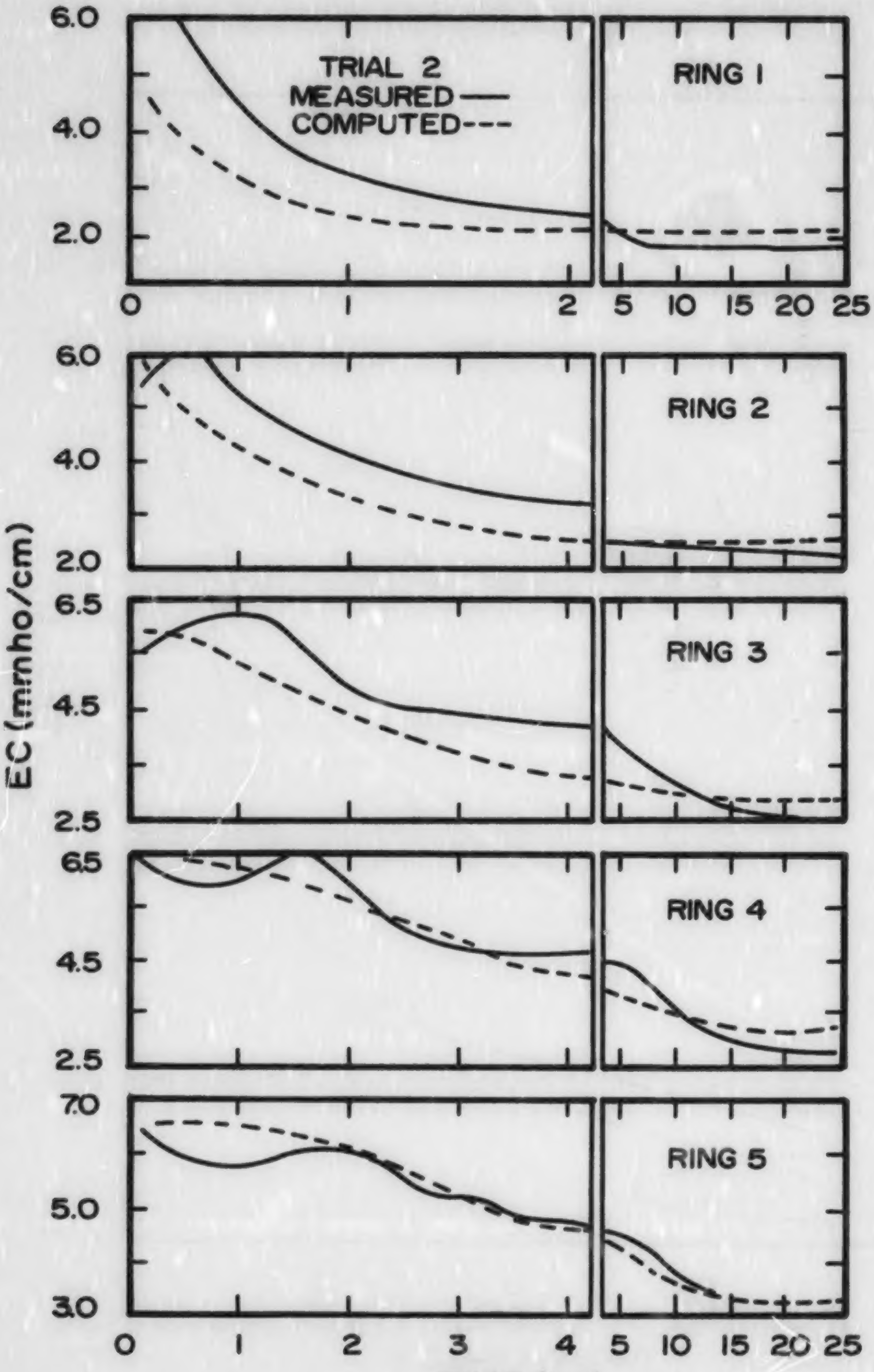


Figure 45. EC computed by the model and by the (4P) vs. time.

applicator that distributed the water on the soil surface (Figure 46). The applicator was a shallow container divided into cells by radial partitions. The cells were divided into the correct radial size to give equal flow onto each part of the soil. This apparatus made possible an even water distribution even at very low water application rates.

The water content in the soil and the bulk density were determined by the gamma ray attenuation method. The gamma ray source and the probe used to make the measurements, were placed in a fixed position and the soil column was placed on an elevator. This made possible the checking of the water content at any desired soil depth by changing the elevation of the column.

Measurements of the electrical conductivity and the volume of the effluent - After completing the experiment, determination of D was made using the data in Table D-1 and the computer program in Appendix D. Once this was completed, another column was prepared in the same way and this column was also leached. This time the leaching was terminated as soon as a few cubic centimeters of effluent had passed the bottom of the column. The column was then separated into its five segments and the EC of the immediate solution extraction was measured. After drying the soil, the EC(1:5) was also measured.

Data from the first column was used to find the D and K parameters and the second column was used to test the validity of the model and parameters that were obtained from effluent data (C[t,Z]) alone.

Trial 3 was conducted on two soil samples, taken from the USU experimental farm in Vernal from two sites. The two replicates, related to the two soil samples are titled as 3A and 3B.

The results of leaching the first column (the main column) of soil from both sites are shown in Table 47 and Table 48. The measurements taken during the irrigation of the second (the reference) columns are in Tables 49 and 50.

D values were computed as before and found to be 4.17 cm^2/hr for sample 3A and 2.2 cm^2/hr in sample 3B. λ values ($D = \lambda|U|$) were 4.3 cm for 3A and 2.7 cm for sample 3B.

The water content was measured periodically by the gamma ray attenuation method and the θ_v values for the intermediate times were interpolated.

The bulk density was calculated as follows: (a) An average value of bulk density of the entire column was determined directly by the weight of the dry soil and the volume of the column. (b) The deviation of the bulk density of each ring from the average was estimated by the gamma ray transmissivity of the dry soil (before irrigation).

The initial water content conditions were uniform at air dry water content.

The total salinity was calculated as follows: $T_s = EC(1:5)X5X\rho_b$.

The initial concentration of the solution was estimated at 10 mmho/cm which was approximately the highest effluent salinity obtained in the leaching process. The initial quantities of the solid salts were calculated as the difference between total salinity and the salinity at the initial solution

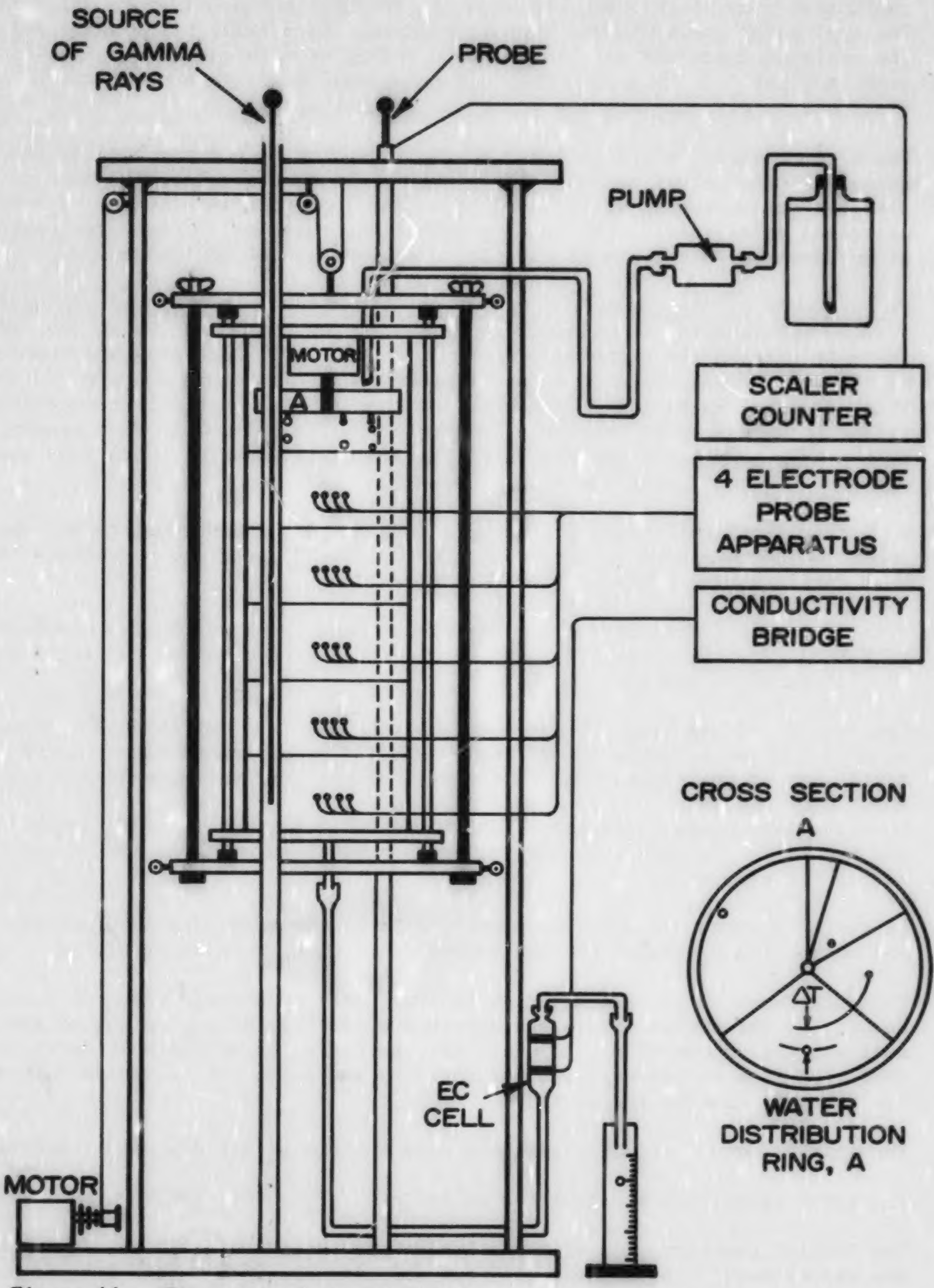

SOURCE OF GAMMA RAYS
PROBE
PUMP
MOTOR
A
SCALER COUNTER
4 ELECTRODE PROBE APPARATUS
CONDUCTIVITY BRIDGE
CROSS SECTION A
ΔT
EC CELL
WATER DISTRIBUTION RING, A
MOTOR

Figure 46. The setup of experiment 3.

TABLE 47. RESULTS OF LEACHING EXPERIMENT NO. 3A

General Data:

L = 24.0 cm
EC influent 1.440 mmho/cm

Ring	1	2	3	4	5
Bulk density g/cm^3	1.318	1.304	1.333	1.377	1.439

t* (h)	Def (cm)	ECef mmho/cm	θ_v 1	θ_v 2	θ_v 3	θ_v 4	θ_v 5	EC(4P) mmho 1	EC(4P) mmho 2	EC(4P) mmho 3	EC(4P) mmho 4	EC(4P) mmho 5	Vda(0) cm/h
0			.021	.021	.021	.022	.023						
2.02			.316	.021	.021	.022	.023	4.3					.612
4.76			.365	.327	.021	.022	.023	4.2	7.0				
7.78			.405	.369	.329	.022	.023	4.2	6.5	6.7			
10.53			.417	.400	.354	.306	.023	4.2	6.0	6.9	7.9		
14.44			.407	.417	.420	.369	.374	4.8	6.3	7.1	9.0	12.2	
15.12			.414	.421	.430	.386	.390	4.8	5.5	6.8	9.0	11.0	
15.68	.43	9.560	.406	.418	.417	.391	.387	4.8	5.5	6.6	8.8	10.2	
17.35	1.12	8.110	.417	.428	.424	.384	.389	4.8	5.5	5.8	8.7	8.7	.474
17.68	1.68	7.800	.405	.421	.407	.369	.358	4.7	5.4	5.5	8.3	8.2	
19.58	2.12	7.550	.401	.438	.423	.403	.387	4.7	5.4	5.3	8.3	8.0	
20.92	2.93	7.260	.412	.415	.426	.388	.373	4.6	5.4	5.2	7.9	7.9	
22.73	3.81	6.930	.429	.416	.414	.380	.378	4.6	5.4	5.1	6.9	7.8	
26.40	5.24	6.230	.435	.427	.431	.402	.385	4.7	5.3	5.0	5.8	7.7	
31.19	7.61	5.560	.448	.429	.417	.385	.384	4.6	5.3	4.8	5.3	5.9	
37.25	10.67	4.040	.408	.418	.415	.395	.381	4.7	5.2	4.8	5.2	4.9	
41.66	12.70	3.350	.400	.417	.449	.381	.383	4.9	5.2	4.7	5.2	4.7	
44.71	14.23	2.930	.419	.414	.417	.401	.365	4.9	5.3	4.7	5.0	4.7	
48.65	16.12	2.350	.385	.405	.422	.395	.383	5.1	5.3	4.7	5.0	4.6	
55.70	19.06	2.100	.455	.422	.433	.402	.385	5.2	5.2	4.7	5.0	4.6	

TABLE 48. RESULTS OF LEACHING EXPERIMENT NO. 3B

General data:

Ring:	1	2	3	4	5
ρ_b (g/cm^3)	1.481	1.354	1.346	1.363	1.342

L = 24. cm
EC influent 1.440 mmhos/cm
Ud = .418 cm/h

t (h)	Def (cm)	ECef mmho/cm	θ_v 1	2	3	4	5
0.00	--	--	.016	.015	.015	.015	.015
2.85	--	--	.300	.015	.015	.015	.015
5.65	--	--	.317	.244	.015	.015	.015
9.21	--	--	.351	.284	.255	.015	.015
12.89	--	--	.371	.303	.312	.242	.015
24.35	.94	4.400	.397	.401	.401	.393	.408
26.59	1.68	3.950	.407	.414	.401	.392	.424
28.99	2.62	3.840	.418	.415	.408	.390	.423
34.27	4.74	3.690	.430	.417	.415	.389	.422
37.88	6.30	3.530	.430	.425	.395	.396	.417
45.37	8.86	3.220	.450	.452	.422	.419	.439
50.61	11.48	2.900	.454	.429	.404	.397	.412
63.45	16.67	2.230	.455	.439	.406	.403	.429
76.00	12.97	1.650	.457	.429	.417	.395	.423
88.17	26.78	1.590	.465	.467	.412	.400	.435

TABLE 49. LEACHING OF THE REFERENCE COLUMN 3A

General data:

Ring:	1	2	3	4	5
Bulk density (g/cm^3)	1.379	1.320	1.344	1.353	1.375

L = 24 cm
EC influent = 1.440 mmho/cm
Ud = .687 cm/h

t (h)	θ_v 1	2	3	4	5	Def (cm)	ECef mmho/cm
0	.022	.201	.022	.022	.022	--	--
2.13	.364	.021	.022	.022	.022	--	--
5.30	.389	.321	.022	.022	.022	--	--
7.72	.417	.384	.345	.022	.022	--	--
10.22	.428	.396	.393	.311	.022	--	--
12.97	.421	.426	.413	.412	.342	--	--
14.02	.471	.437	.439	.436	.413	.01	9.700
14.97*	.439	.427	.454	.429	.421	.43	8.270

EC (1:5 extraction) of original soil 420 μmho

Ring	1	2	3	4	5
EC of immediate extraction in the end μmho/cm	3040	4020	5900	7400	7600
EC of 1:5 extraction in the end μmho/cm	250	310	500	620	730
Solid salt (μmho/cm)	327	365	846	1197	2016

*Gravimetric test

TABLE 50. LEACHING OF THE REFERENCE COLUMN 3B

General data:

Ring:	1	2	3	4	5
Bulk density (g/cm^3)	1.439	1.368	1.377	1.406	1.453

L = 24 cm
EC influent = 1.440 mmho/cm
Ud = .425 cm/h

t (h)	θ_v 1	2	3	4	5	Def (cm)	ECef mmho/cm
0.00	.016	.015	.015	.015	.016		
3.58	.276	.015	.015	.015	.016		
6.33	.295	.235	.015	.015	.016		
9.08	.328	.260	.230	.015	.016		
12.16	.330	.279	.290	.235	.016		
22.58	.385	.371	.378	.370	.381	.92	4.400
22.58*	.393	.363	.377	.371	.385		

Ring	1	2	3	4	5
EC of immediate extraction in the end (μmho/cm)	200	225	250	260	320
EC of 1:5 extraction (μmho)	1700	1820	2450	2850	2950
Solid Salt per 1 cm^3 of soil	764	879	979	771	1189

*Gravimetric test

and were expressed as solid salts per unit volume of soil. The boundary conditions at the soil surface were determined so that the salt flow at the soil surface would be equal to the rate that salt in the influent entered the soil or:

$$- D_o \left(\frac{\partial C}{\partial z}\right)_o + q_o C_o = q_o C_{ir} \qquad [20]$$

The numerical approximation of [20] is:

$$C_1^{j+1} = C_2^{j+1} \left(\frac{2D_1 \left(1 + \frac{DLXA}{DLXB}\right)}{3D_1 + 2q_1 \, DLXC}\right) + C_3^{j+1} \left(\frac{2D_1 \left(0.5 - \frac{DLXA}{DLXB}\right)}{3D_1 + 2q_1 \, DLXC}\right) + W$$

where DLXA = $z_2 - z$, DLXB = $z_3 - z_2$, DLXC = $(z_3 - z_1)/2$

and $W = \frac{2D_1}{3D_1 + 2q_1 DLXC} \left[C_1^j \left(-1.5 - \frac{DLXC \; q_1}{D_1}\right) + C_2^j \left(1 + \frac{DLXC}{DLXB}\right)\right.$

$$+ C_3^j \left(0.5 - \frac{DLXA}{DLXB}\right) + 2\ DLXC\ q_1\ C_{ir}]$$

The boundary condition at the bottom was $\left(\frac{\partial C}{\partial z}\right)_{z=Z} = 0,\ C_N = C_{N-1}$

Applying the above boundary condition to equation [11] the first equation in the set is:

$$C_2^{j+1}\left[b + \frac{2D\left(1 + \frac{DLXA}{DLXB}\right)}{3D + 2q\ DLXC}\right] + C_3^{j+1}\left[C + \frac{2D\left(0.5 - \frac{DLXA}{DLXB}\right)}{3D + 2q\ DLXC}\right]$$

$$= d - \frac{2D}{3D + 2q\ DLXC}\left[C_1^j\left(-1.5 - \frac{DLXC\ q_1}{D}\right) + C_2^j\left(1 + \frac{DLXA}{DLXB}\right)\right.$$

$$\left. + C_3^j\left(0.5 - \frac{DLXA}{DLXB}\right) + 2\ DLXC\ q\ Cir\right] \qquad [21]$$

and the last equation in the set:

$$C_{N-1}^{j+1}a + C_N^{j+1}(b+c) = d. \qquad [22]$$

In spite of partial success in calibrating the four-probe electrode, this method of measuring salinity was not considered reliable enough to use for the entire soil column. Therefore, the computations are based on the effluent data only. The detailed program that solves this system of equations can be found in Appendix D.

Because of the length of the computer time required for the program, the optimal K is not found by the program itself. Each trial of K needed a special run of the whole program.

Figures 47 and 48 show the measured and the computed EC of the effluent. In both cases the model simulated the data with reasonable accuracy but the shape of the measured durve was not simulated too well. In both cases the biggest deviation from the measured data occurred at the beginning of the process (as in trial 1). The measured data at the beginning were considerably higher than the computed. It is probable that the poor simulation in the first stage of leaching is a limitation of the model in that it treats the different salt species as if they were one salt with average properties.

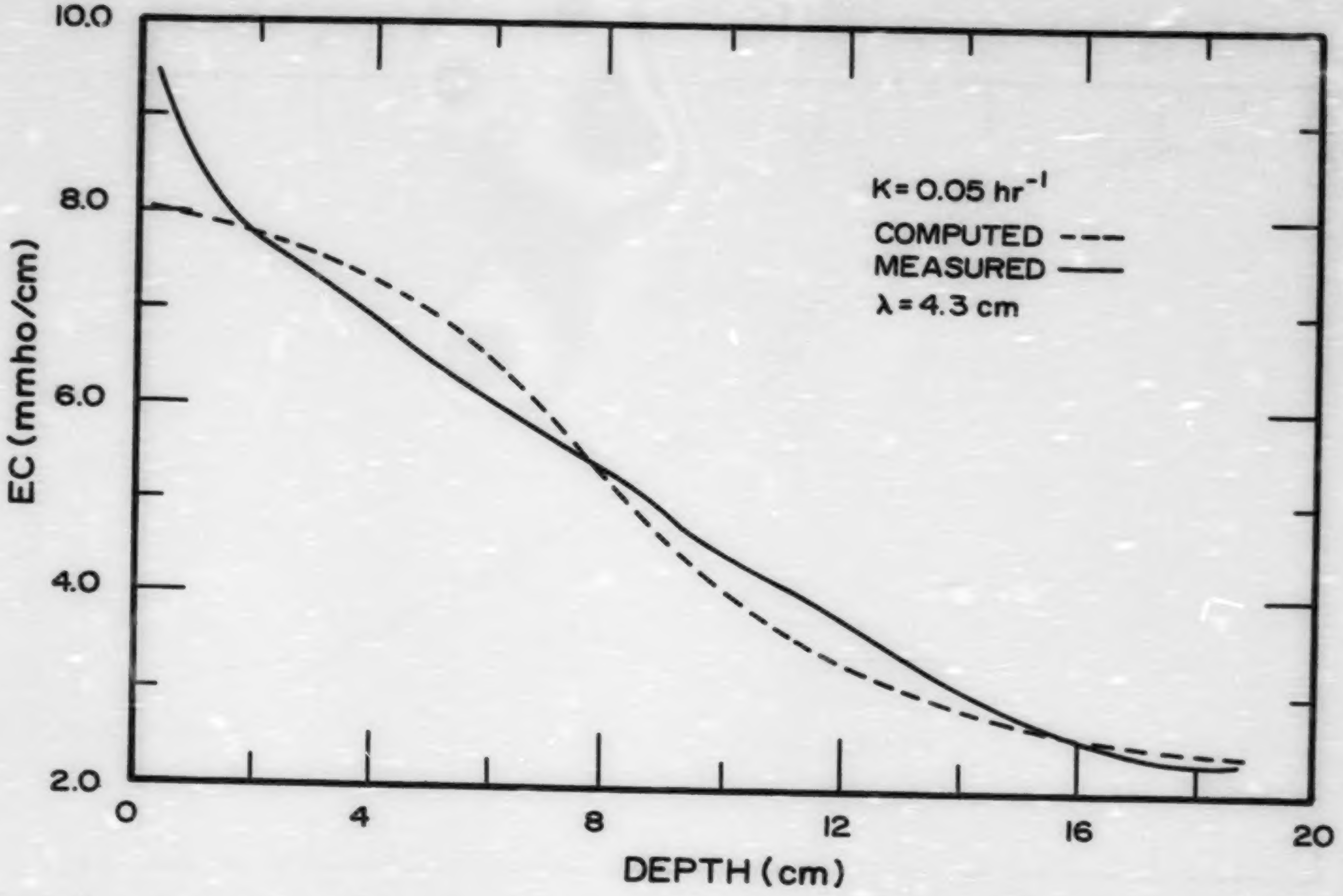


Figure 47. The computed and the measured EC of the effluent vs. the depth of the effluent - laboratory trial 3.

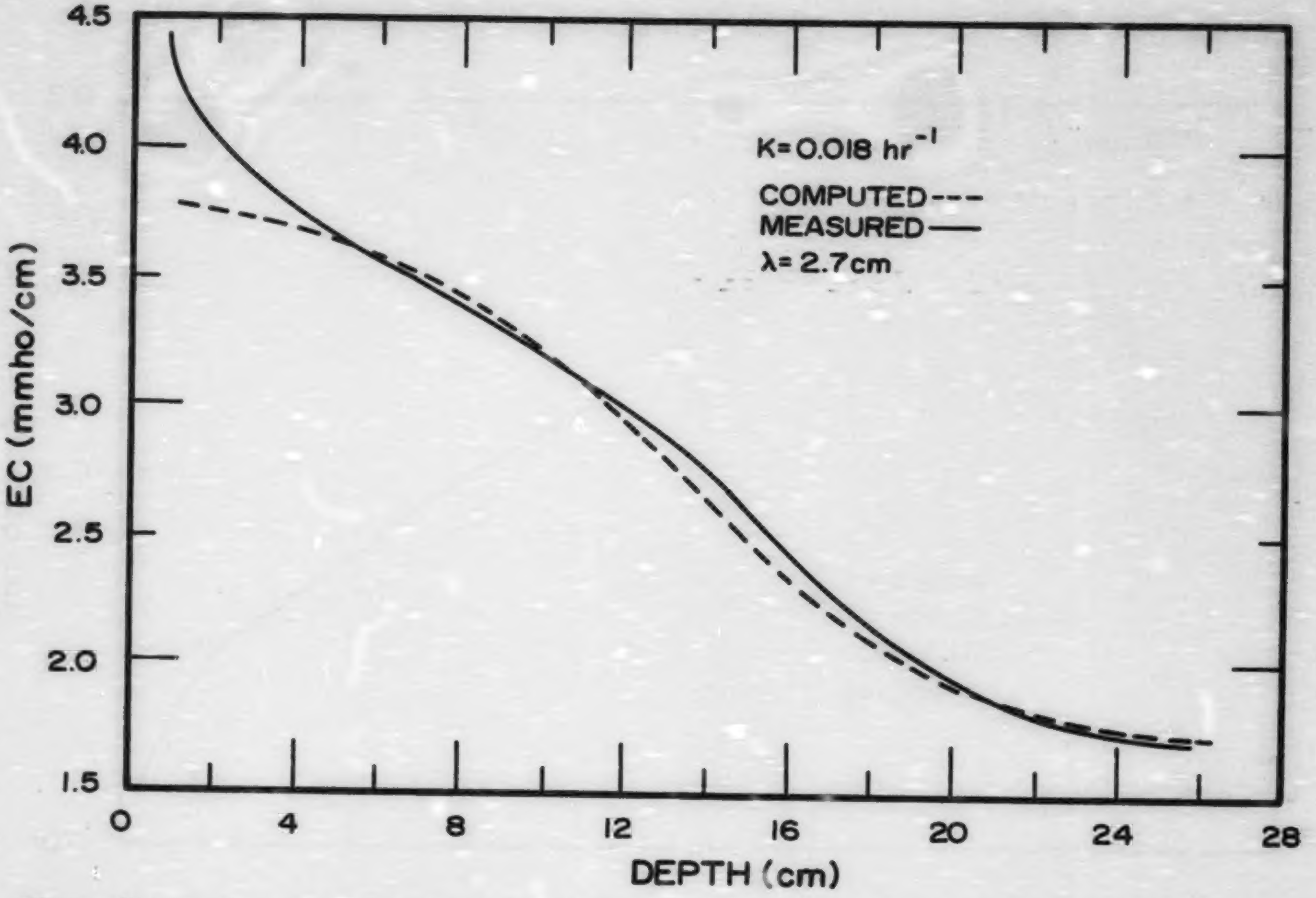


Figure 48. The computed and the measured EC of the effluent vs. the depth of the effluent - laboratory trial 3.

The K and D parameters, obtained in the main column, were applied to the reference columns and the salinity profile was computed. Figures 49 and 50 show the computed and the measured salinity of the soil profile. The simulation is reasonably good. In both cases the model simulated the total salinity better than it simulated each of the components (the solution and the solid salt). In both cases the solid salt was underestimated in the upper half of the profile and overestimated in the bottom half of the profile.

TESTING THE SOURCE-SINK MODEL UNDER FIELD CONDITIONS

The objective of this part of the research was to test whether data obtained in the field could be simulated by the model.

The same source-sink term that was developed for the laboratory columns was added to a water movement model (Hanks, et al., 1969) to simulate salt movement under field conditions. The experimental data were obtained from a field trial performed at the Vernal experimental farm. The field trial is fully described by King and Hanks (1975) (see field trial 1 in that report).

The computations were done in the following order: (1) data were simulated without using a sink-source term; (2) data were simulated using a source-sink term with uniform parameters for the whole profile; and (3) data were simulated using a different R value for the reference equilibrium concentration for each soil layer.

In order to determine values of R in the field, it must be assumed that the solid salts and the salts in the soil solution are close to an equilibrium state. In this situation, the R value is equal to the concentration of the soil solution at a particular depth. Thus the R values assigned to the source-sink term are equal to the initial soil solution salinity conditions. The test to determine whether the source-sink term is significant is made by comparing the quantities of salt existing in the natural soil solution to the quantity obtained by 1:5 extraction, which is used as a measure of total salinity. If the salt quantities are equal, a value of zero is assigned to K. The same value of K, 0.05, found by trial and error to fit the laboratory data, was used for all the field computations.

The detailed results comparing the measured and simulated data computed in the three different ways can be found in Table 51.

Figures 51 and 52 show the salinity profiles that were computed in the three different ways compared to measured salinity profiles. The model that neglected the source-sink phenomenon overestimated the salinity when the concentration of the influent was higher than the concentration of the soil solution (Figure 51). When the soil solution was displaced by an influent with a lower concentration, the salinity was underestimated (Figure 52) and the upper part of the profile was simulated better than the lower part. This was attributed to there being less solid residual salts in the upper layers than are present in the lower layers. This result supports the argument that

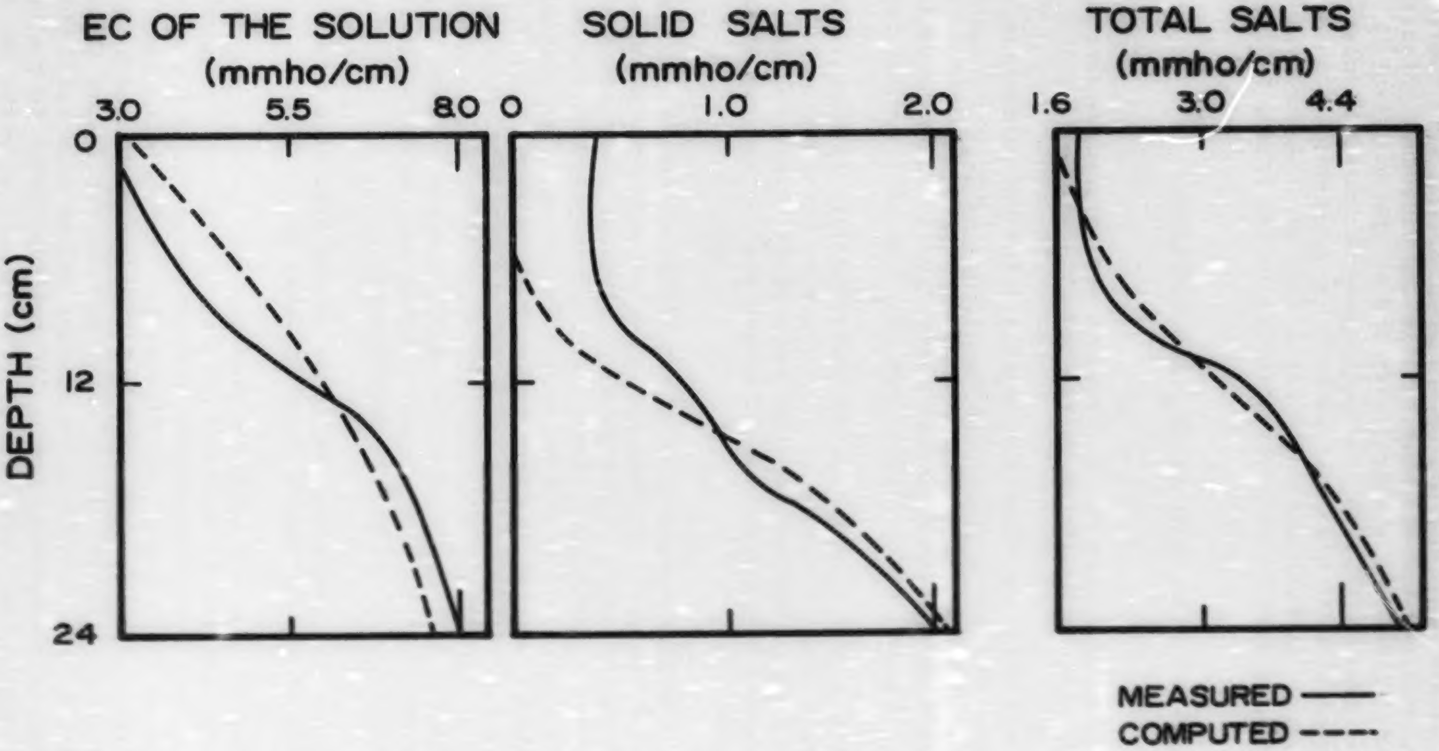


Figure 49. Measured and computed salinity vs. depth in the reference column - laboratory trial 3.

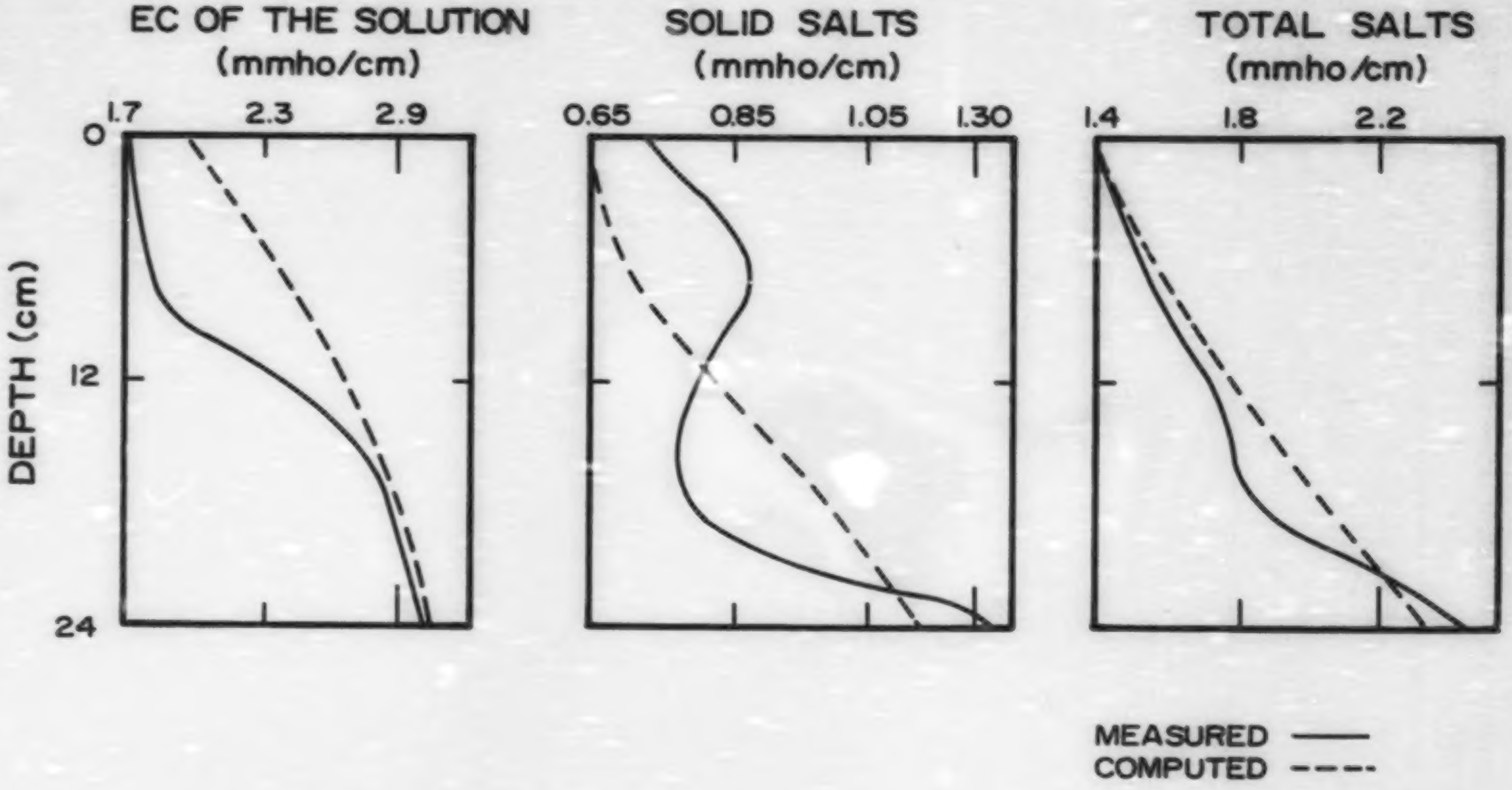


Figure 50. Measured and computed salinity vs. depth in the reference column - laboratory trial 3.

TABLE 51. MEASURED AND COMPUTED EC OF THE SOIL SOLUTION IN SEVERAL TIME POINTS.

Time: 0 - 0.5 hr 10 cm water (EC = 8.0 mmho/cm) added

Time: 2.5 hr

Depth (cm)	Measured	First Computation	Second Computation	Third Computation
		mmhos/cm		
0 - 30	6.2	8.0	5.9	7.0
30 - 60	6.3	7.7	5.2	6.7
60 - 90	5.5	5.9	5.1	5.6
90 - 120	4.2	5.7	5.0	4.7
120 - 150	3.3	6.7	5.1	3.9
150 - 180	2.0	5.1	4.4	3.2
Time: 10.0 hr				
0 - 30	7.0	8.0	5.8	7.0
30 - 60	6.5	7.9	5.0	6.6
60 - 90	5.3	6.1	5.0	5.5
90 - 120	4.3	5.6	5.0	4.6
120 - 150	3.8	6.6	5.0	3.7
150 - 180	217	5.6	4.4	3.1
Time: 24.5 hr				
0 - 30	6.3	8.0	5.8	7.0
30 - 60	7.1	8.0	5.0	6.6
60 - 90	6.2	6.3	5.0	5.5
90 - 120	4.7	5.6	5.0	4.6
120 - 150	3.8	6.4	5.0	3.7
150 - 180	2.7	5.4	4.3	3.1
Time: 24.75 - 25.75	25 cm water (EC = 4.1 mmho/cm) added			
Time: 26.25				
0 - 30	7.2	4.1	4.4	5.0
30 - 60	6.8	4.1	4.6	5.6
60 - 90	5.5	4.1	4.7	5.3
90 - 120	4.0	4.2	4.8	4.9
120 - 150	3.2	5.8	4.9	4.6
150 - 180	2.9	6.4	4.6	4.1

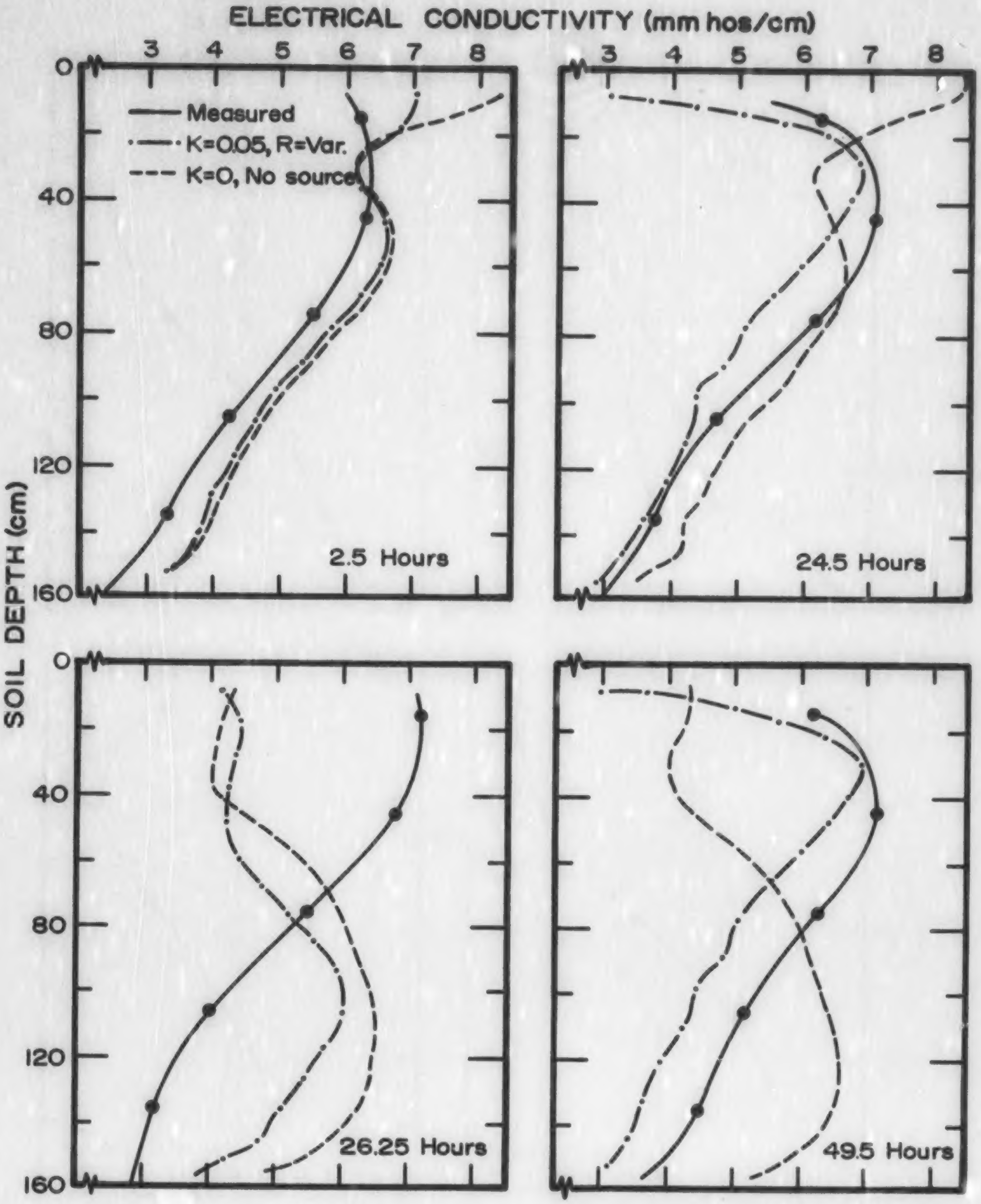


Figure 51. Measured and simulated comparison using no source-sink term (K = 0.0) and a variable source-sink term for the Vernal field trial.

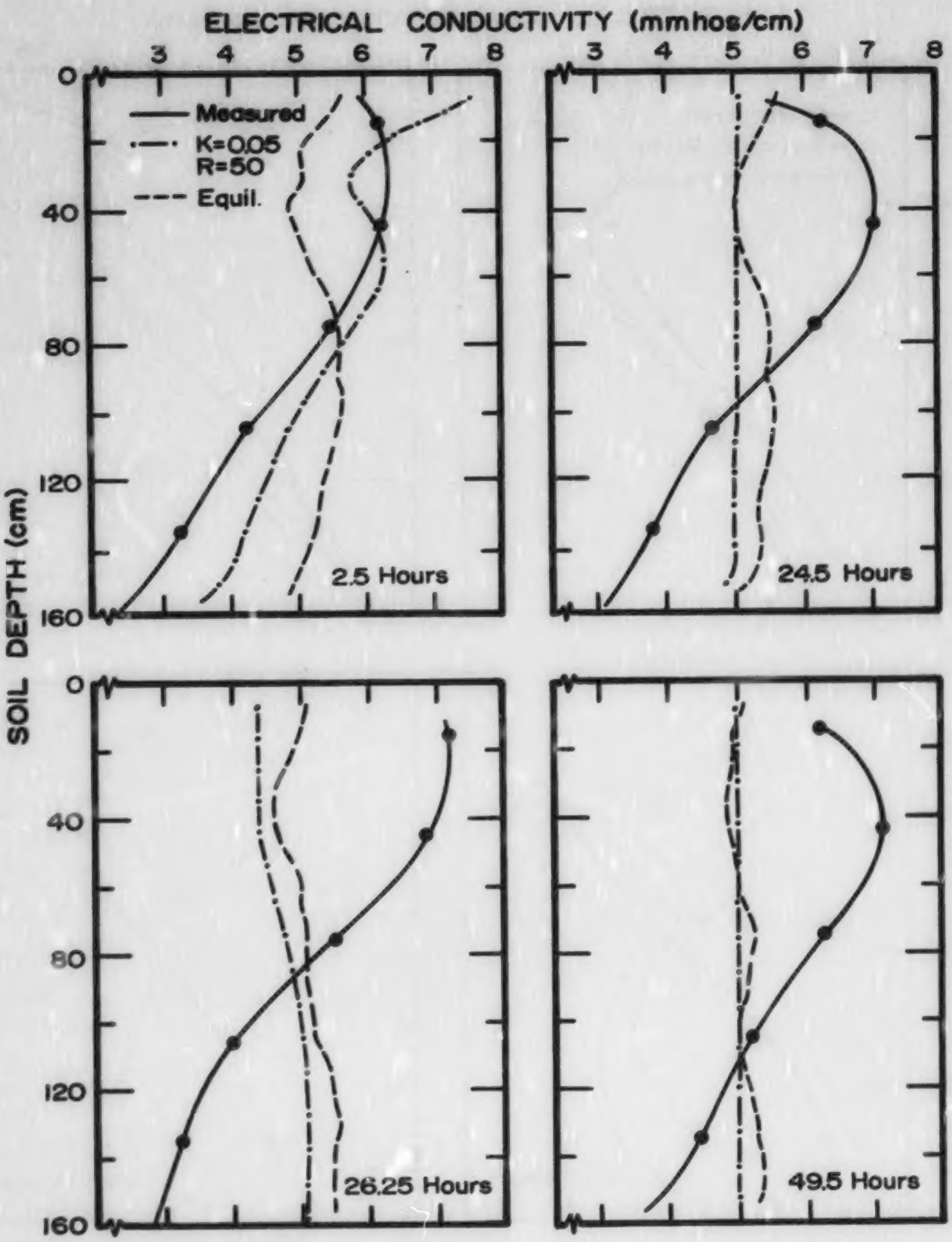


Figure 52. Measured and simulated comparison using a constant source-sink term and chemical equilibrium model for the Vernal field trial.

the soil manifests "buffering" characteristics and that a sink-source term should be included in the model in order to improve the salt distribution predictions. This soil is probably representative of a non-leached arid zone soil where large quantities of soluble salts are present in the solid state.

Computations using a source-sink term with constant K and R parameters for the whole soil profile for the field data (as was done in the lab trials 1, 2, 3) improved the prediction of the total salts in the soil solution of the entire profile but still predicted the salt distribution with depth (Figure 51) very poorly. This is because the salt content of the soil profile in the field was not initially uniform. By using a different coefficient for each layer in most of the cases (except for Figure 51) the model predicted the measured data fairly well.

MODEL PREDICTIONS OF SALINITY EFFECTS ASSUMING NO SOURCE-SINK

The report of King and Hanks (1975) shows predictions made by their model where variables of initial soil salinity, amount of irrigation, and crop root depth were studied. Some limited computations were also made to determine the influence of salt buildup on yield over several years. Using the same model, additional predictions have been made in this study where the quality of the irrigation water, irrigation uniformity and time are important variables. All other details of the computations are the same as given by King and Hanks (1975).

Irrigation Water Quality

Predictions of salinity effects on yield were made where irrigation amount, initial soil salinity, and root depth were variables, as given in King and Hanks (1975), and where another variable, irrigation water quality was added. Figure 53 shows an example of the results of these computations. The data show, that for low amounts of irrigation and rain, the best quality irrigation water gives higher relative yield than the poor quality irrigation water. However, as the amount of irrigation water increased, there was less difference in yields due to irrigation water quality differences. As shown by King and Hanks (1975), high initial soil salinity decreased yields. The model predicts that even with irrigation water of very low quality (C_{iw} = 100 meg/l = EC = 10 mmhos/cm or about -3.6 bars matric potential) good yields are obtained if irrigation amounts are high. This result may be questionable and needs to be field tested.

Figure 54 shows the effect of amount of irrigation water applied where upward flow or drainage may occur and where irrigation water quality and initial soil salinity was varied. Upward flow and drainage was the same for both irrigation water qualities for high and low water applications. At intermediate water applications (16 in) (40 cm), the more saline irrigation water resulted in more upward flow than the less saline irrigation water. For a given amount of water applied the higher the initial soil salinity the lower the amount of upward flow.

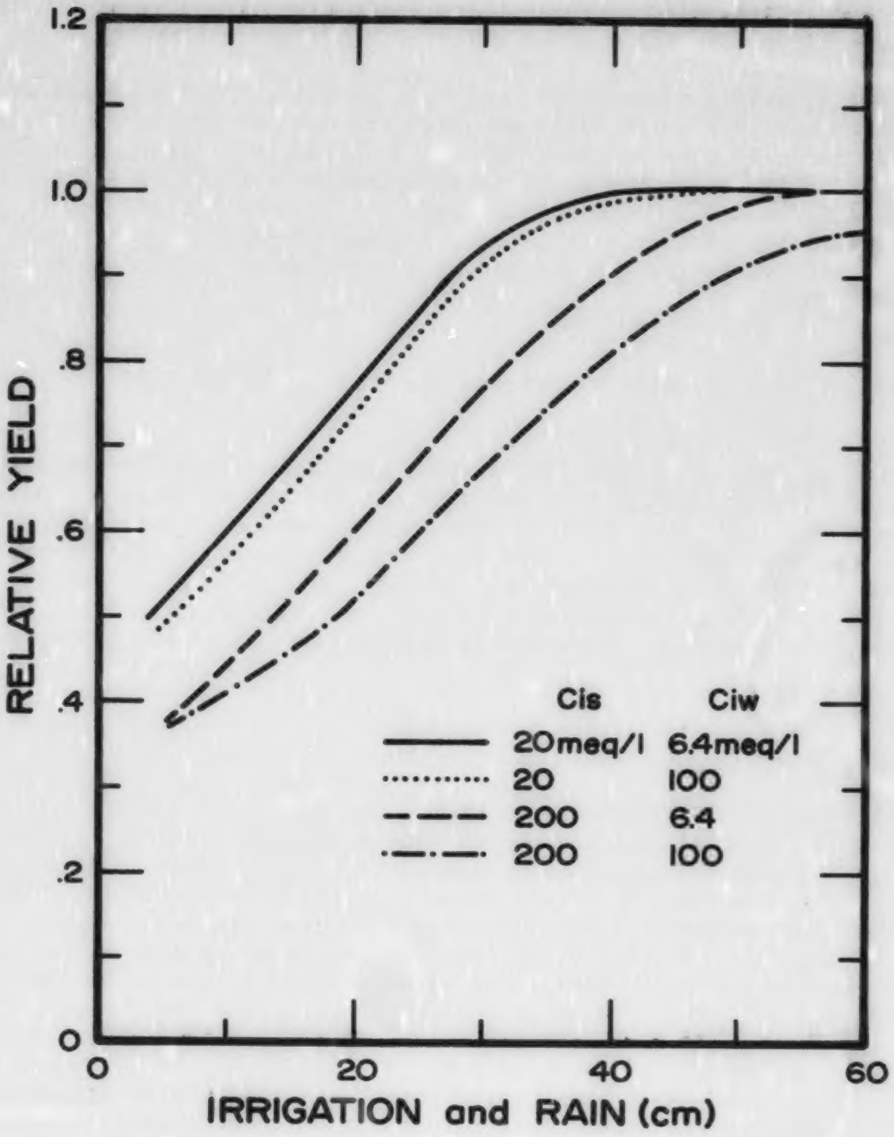


Figure 53. Relative yield as related to the amount of irrigation and rain, concentration of the irrigation water (C_{iw}), and initial soil solution concentration (C_{is}) for a medium rooted crop.

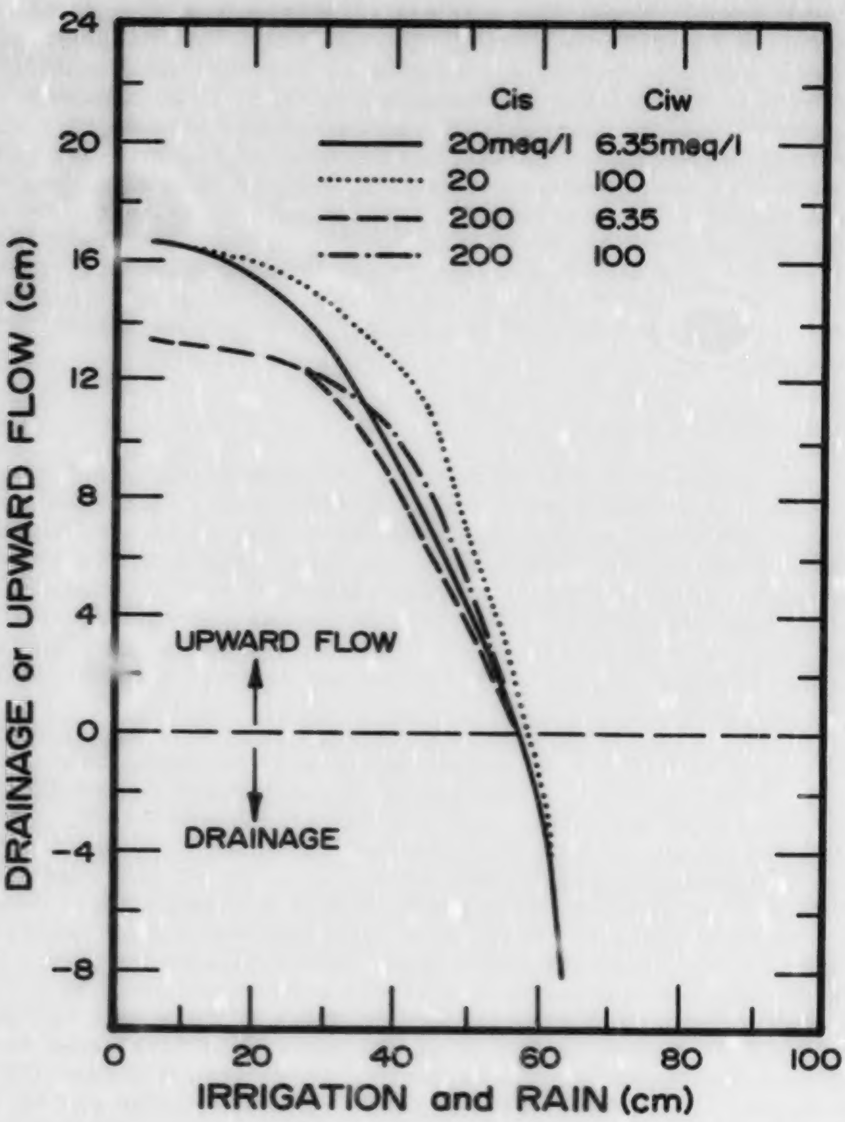


Figure 54. Upward flow and drainage versus irrigation and rain for deep rooted crops at two water qualities and two initial soil salinities.

An additional effect of irrigation water quality as shown by the model is its influence on the general shape of the soil salinity profile. Relationships between the soil salinity concentration profile, irrigation water quality, amount of irrigation and initial soil salinity are shown in Figure 55 for a medium root depth crop. Figure 55 shows the effects of water quality on the salinity profile for different irrigation amounts. Under low irrigation amounts large near-surface concentrations were established while the remainder of the salinity profile was increased slightly. With high irrigation amounts, the tendency was to form uniform concentrations with depth. There was, in general, no accumulation of salt at the base of the root zone. Figure 55 shows the effect of water quality at two initial profile salinities with high irrigation amounts. The results for the low initial salinity are similar. The results for higher level of initial soil salinity were different since the irrigation waters were all less saline than the soil solution. Therefore, the upper portion of the profile had a somewhat lower concentration than the rest of the root zone. The best quality irrigation water was most efficient in the leaching process.

Multi-Year Calculations

The calculations for a single year show that, although yield is not affected immediately, substantial increases in soil salinity occur under some conditions of water and salt management. If these management conditions are viewed as farm operation schemes, it is clear that yield for a single season cannot be the only criterion in choosing particular water and salt treatments. In order to examine the long-term effects, predictions have been made in cumulative fashion for periods up to 10 years. This provides data for assessing the importance of various soil water management variables in long-term planning.

Assessment of long-term effects of various management practices was accomplished by using the final conditions of a single-year run as initial conditions for the following year. Boundary conditions assumed for irrigation, rain, and potential evapotranspiration remained the same; soil water content was assumed to be roughly at field capacity at the start of each new year. Figure 56 shows typical results for several 10-year sequences for a deep-rooted crop. Relative yield and final soil salinity are plotted together in order to show the close relationship which exists between the two. None of the irrigation amounts applied were sufficient to cause leaching so there was a salt accumulation on all treatments. In spite of this salt buildup, there were no yield decreases predicted at the end of the first year for any of the three water application treatments. Where only 6 inches (15 cm) of water were applied each year, yield began to decrease at the end of the second year and continued to decrease throughout the period. Where 9.5 inches (24 cm) of water were applied each year, salinity buildup did not cause yield reduction until after the sixth year. Where 17 inches (43 cm) of water were applied each year, there was not sufficient salt buildup to cause a yield decrease even at the end of 10 years.

The high yields shown by the model and obtained in the field with relatively small amounts of irrigation water applied may be unique to the Vernal field situation because of the large amount of upward flow that occurs (also shown

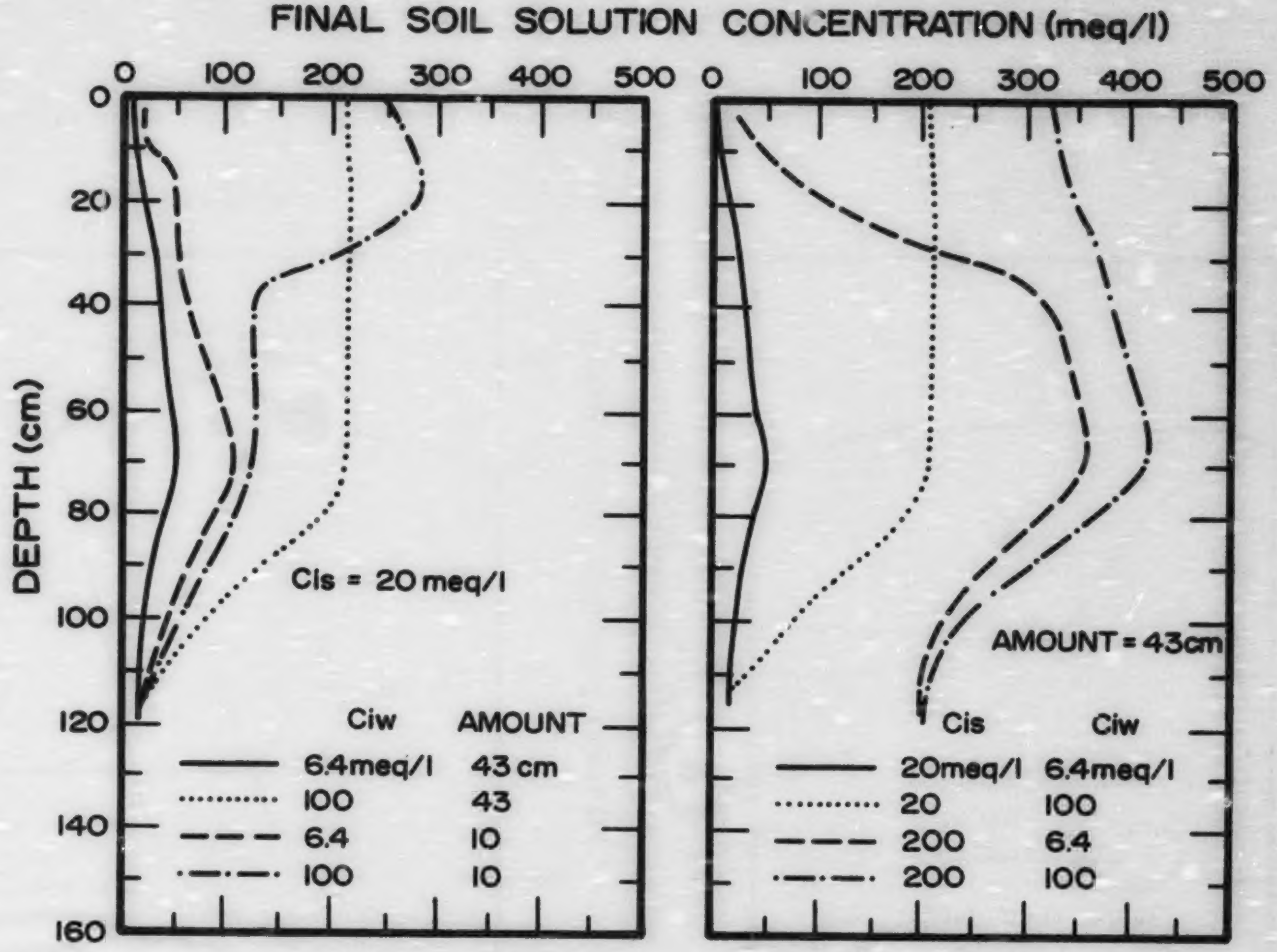


Figure 55. Final soil solution concentration predictions as influenced by concentration of the irrigation water (C_{iw}), the amount of irrigation applied and initial soil solution concentration (C_{is}).

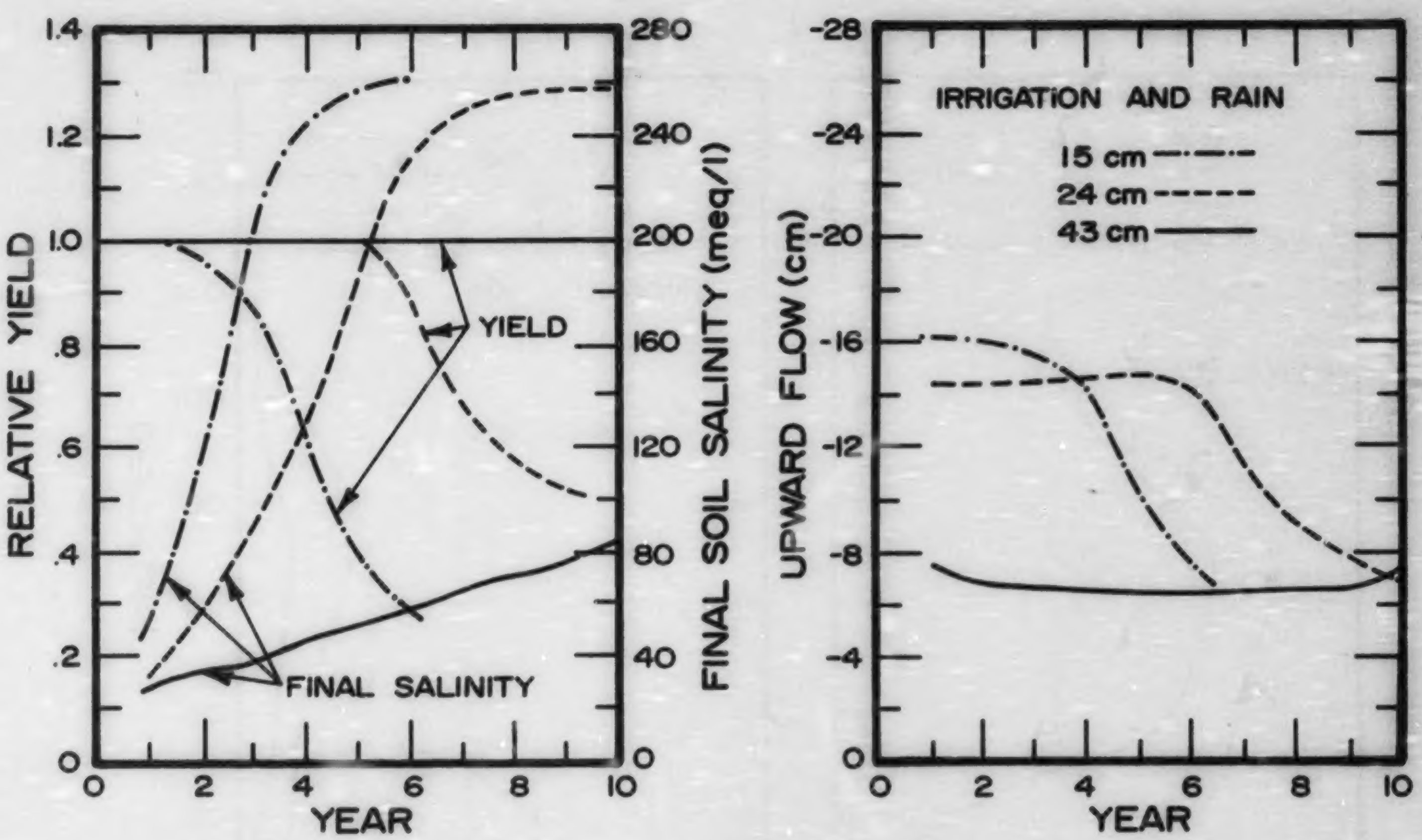


Figure 56. Relative yield, final salinity, and upward flow versus time for the deep rooted crop. Irrigation water quality: 6.4 meq/1.

in Figure 56). As salt buildup occurred with increasing time in the model for the two lowest levels of applied water, the amount of upward flow was relatively constant until yield reductions began, at which time the amount of upward flow decreased.

Figure 57 shows predicted final soil salinity profiles versus time for a medium root depth crop. The same quantity of water, 17 inches (43 cm), was applied in each case. This amount of water would not cause leaching. All of these data show expected trends. Soil salinity increased almost uniformly throughout the root zone. The effect of increasing irrigation water salinity was to hasten salinization of the soil profile and raise the maximum concentration.

Calculations regarding uniformity of water applications - A final arrangement of the basic data was made in order to show the effects of uniformity of water application on yield. While the predictions of this model can show that a particular irrigation rate is ideal for a given situation of soil salinity, irrigation water quality, and crop type, application of that precise amount of water everywhere in a field is virtually impossible. In order to simulate this variability, a measure of uniformity of water application was required. The approach used was to segregate an area into zones receiving differing amounts of irrigation according to the uniformity afforded by the water application system. Separate calculations were carried out for each of these zones and were then combined to give general results for the entire area. The measure of water application uniformity commonly used was:

$$Cu = 1 - \frac{D}{M} \qquad [23]$$

Where:

Cu = Coefficient of Uniformity
M = Average of Ideal Irrigation
D = Average Deviation from M (disregarding sign)

when the coefficient of uniformity equals 1, the average deviation is zero and the ideal irrigation amount is applied everywhere. A rule of thumb to clarify this concept is: Approximately 79 percent of the irrigated area receives an irrigation equal to or greater than the amount (Cu X M). (Equation [23] is a variation of Equation [4]).

In order to completely specify an irrigation amount for any small area, the pattern of distribution of the water application within the 79 percent of the area must be known. For the purposes of this project, two patterns of distribution were considered: rectangular and parabolic (Figure 58). For a rectangular distribution, the same amount of area receives minimum irrigation as that which receives the ideal amount. The parabolic distribution has most of its applications clustered near the ideal. In other words, given the same value for Cu, a parabolic distribution has more of the total land receiving nearly ideal irrigation than does the rectangular distribution.

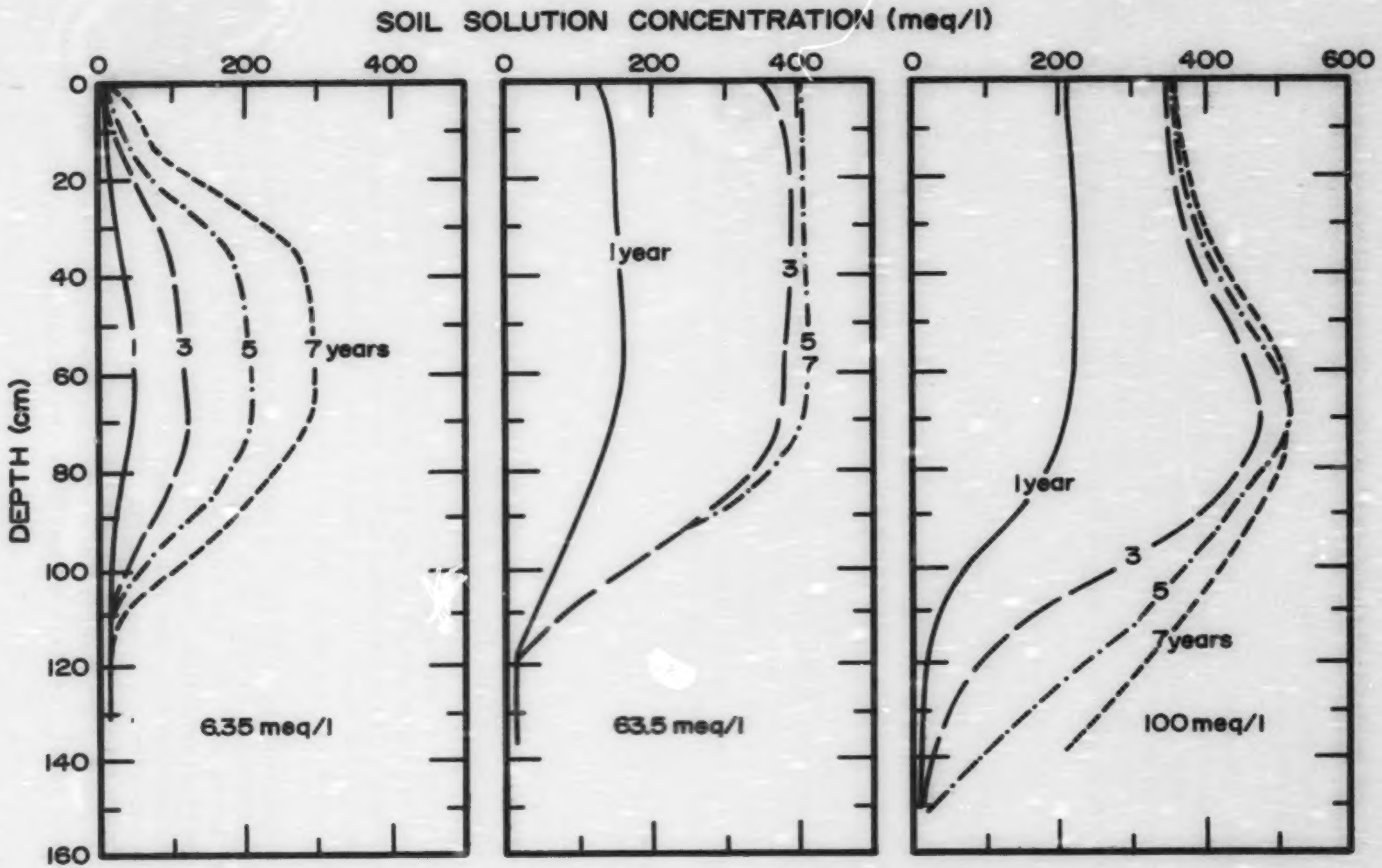


Figure 57. Predicted final soil salinity versus depth for the medium rooted crop at various times and at three irrigation water qualities.

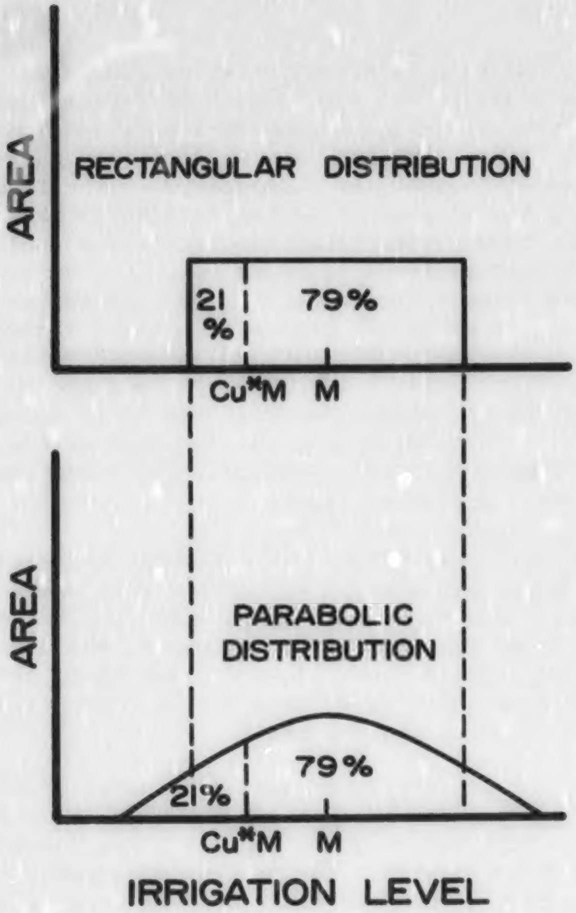

AREA
RECTANGULAR DISTRIBUTION
21 %
79%
Cu*M
M
AREA
PARABOLIC DISTRIBUTION
79%
21%
Cu*M
M
IRRIGATION LEVEL

Figure 58. Patterns of distribution for uniformity calculations.

Using the concepts of coefficient of uniformity and pattern of distribution, a variety of probable irrigation patterns were investigated. The sprinkler system for the experimental farm at Vernal, Utah, has a measured Cu value of 0.88 that can be approximated by a parabolic distribution pattern. This was the most controlled irrigation application considered. The other extreme of the range of uniformities was a rectangular distribution with Cu = 0.42. This option was assumed to simulate the flood irrigation system previously in use at Vernal, Utah.

Table 52 shows the data from calculations which consider irrigation uniformity. The total area is divided into 5 blocks with different irrigation levels that depend on uniformity. A comparison of the irrigation amounts in the two portions of the table shows that low uniformity causes a wide range in the irrigation application amounts. Comparison of the figures for area show that, in addition to the wide range of the irrigation amounts for Cu = 0.42, the extremes include more of the area. The areas are used to weight the results for each irrigation level in order to obtain an average figure. The remainder of the table shows the individual results for the 5 blocks for two times. Initially, a projected change from flood irrigation to sprinkler irrigation (a rectangular parabolic pattern) boosted yields from 83 percent to 95 percent of maximum yield. After 5 years, average yield was still at 95 percent under sprinkler irrigation while the yield under flooding has dropped to 80 percent. Another predicted advantage of the sprinkler system can be seen in the figures for salt outflow. The predicted better irrigation management gave a smaller salt outflow.

Figure 59 shows the multiyear effects of different irrigation system uniformities on relative yield and salt outflow with equal water applications of 21 inches (53 cm). Although the average water applied was sufficient to cause leaching, there was a net salt buildup in the areas not leached because of non-uniform application. This did not cause appreciable yield decreases in the 10 years simulated. However, a sharp rise in salt outflow occurred for Cu = 0.42 after about 7 years.

Uniformity options as presented above should be considered in relation to all appropriate soil-plant phenomena and should be used as another management option in planning. Uniformity can be generally considered as a measure of control of the soil-plant system. For precise management of an area, the above results indicate that the coefficient of uniformity should be high. Practical limitations may preclude high uniformity. The model allows calculations of intermediate schemes of uniformity, water application, and salt management in addition to those presented. These schemes need not be concerned with only achieving ideals but may also be used to predict the consequences of various existing or proposed management schemes. This kind of data would also be useful in planning a minimum cost irrigation system which will meet given production, environmental quality, and water specifications.

TABLE 52. EXAMPLE OF UNIFORMITY CALCULATIONS - 5-YEAR SEQUENCE FOR THE SHALLOW ROOTED CROP

Irrig. and rain cm	% Area	Rel. yield	Salt outflow T/ac	Final soil salinity meq/l	Rel. yield	Salt outflow T/ac	Final soil salinity meq/l
YEAR 1					YEAR 5		
Cu = 0.88 Parabolic distribution					Irrigation and rain: 53.1 cm		
40.4	10.4	.85	-	27.6	.84	-	70.8
46.7	24.8	.92	-	25.7	.91	-	52.5
53.1	29.6	.96	-	23.9	.96	-	38.7
59.5	24.8	.99	.23	22.4	.99	.03	29.6
65.8	10.4	1.00	.55	21.2	.99	.64	24.0
AVERAGE		.95	.11		.95	.14	
Cu = 0.42 Rectangular distribution					Irrigation and rain: 53.1 cm		
10.6	20.0	.50	-	32.3	.39	-	161.6
31.9	20.0	.75	-	29.9	.68	-	50.5
53.1	20.0	.96	-	23.9	.96	-	38.7
74.3	20.0	.96	1.14	20.4	.96	1.19	21.1
95.6	20.0	1.00	3.63	20.0	1.00	3.86	20.0
AVERAGE		.83	.97		.80	1.02	

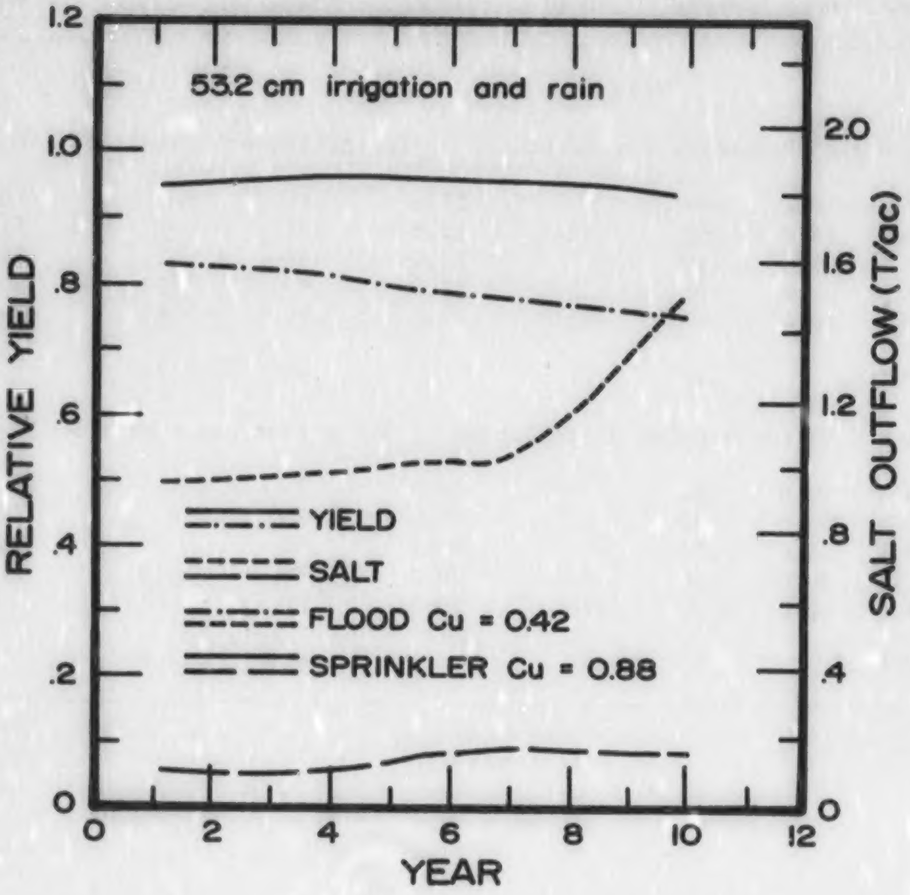


Figure 59. Relative yield and salt outflow versus time for two coefficients of uniformity.

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APPENDICES

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APPENDIX A

IRRIGATION SCHEDULING COMPUTER PROGRAM[1]

This program is written in FORTRAN IV for a Univac 1108 time-sharing computer. It will handle 4 regions with a maximum of 100 fields.

Flow Chart

A summary flow chart for the program is shown in Figure A-1.

Area Constants

For operation, several area constants must be determined. For forecasting potential ET, the maximum potential ET, E'_{tp}, for the area must be known. Also the Julian calendar day, t', when this maximum occurs (about July 15 to July 25 in the northern hemisphere), and Δt, the days before and after t' when potential ET = $0.37\ E'_{tp}$ must be determined. Wind coefficient, CW, must be adjusted for anemometer height (0.0170 for 12 feet, 0.0135 for 2 meter, etc.). Experimental coefficients used for the net radiation equation, line 28 subroutine VAPOR, are given in Table A-1. In addition, clear day solar radiation for the regions of interest must be known. Table A-2 gives the area constants evaluated for Vernal, Utah. Figure A-2 gives the clear day solar radiation for Vernal, Utah, as determined from incoming daily solar radiation.

TABLE A-1. EXPERIMENTAL COEFFICIENTS FOR NET RADIATION EQUATION

Region	(a	b)
Southern Idaho	(1.22	-0.18)[1]
General	(1.20	-0.20)[2]
General	(1.00	0.00)[3]

[1] Wright, J. L. and M. E. Jensen (in press)

[2] Suggested for arid areas

[3] Suggested for humid areas

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[1] Contribution from the Northwest Branch, Soil and Water Conservation Research Division Agricultural Research Service, USDA, Kimberly, Idaho, 83341. Revised by Ronald D. Bliesner, 1974.

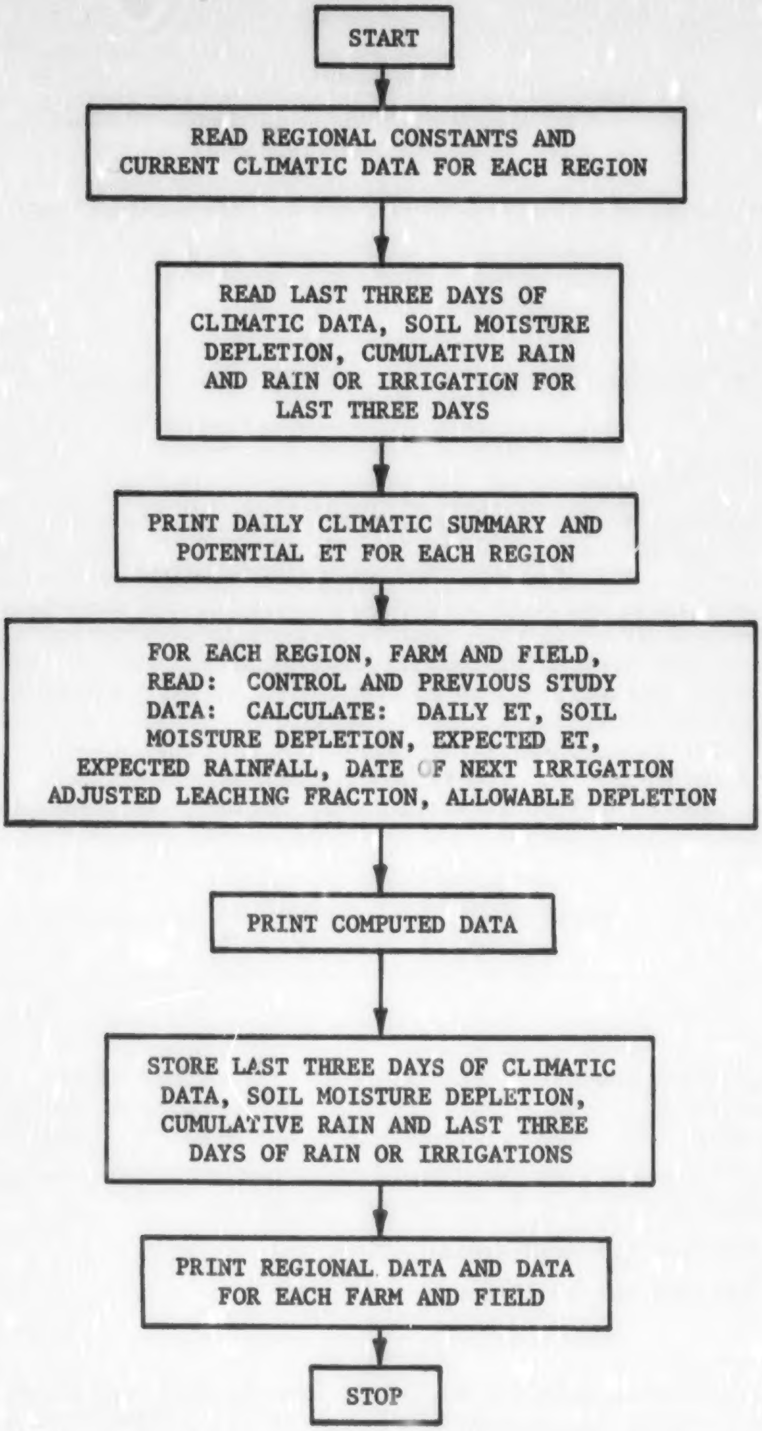
START
READ REGIONAL CONSTANTS AND CURRENT CLIMATIC DATA FOR EACH REGION
READ LAST THREE DAYS OF CLIMATIC DATA, SOIL MOISTURE DEPLETION, CUMULATIVE RAIN AND RAIN OR IRRIGATION FOR LAST THREE DAYS
PRINT DAILY CLIMATIC SUMMARY AND POTENTIAL ET FOR EACH REGION
FOR EACH REGION, FARM AND FIELD, READ: CONTROL AND PREVIOUS STUDY DATA: CALCULATE: DAILY ET, SOIL MOISTURE DEPLETION, EXPECTED ET, EXPECTED RAINFALL, DATE OF NEXT IRRIGATION ADJUSTED LEACHING FRACTION, ALLOWABLE DEPLETION
PRINT COMPUTED DATA
STORE LAST THREE DAYS OF CLIMATIC DATA, SOIL MOISTURE DEPLETION, CUMULATIVE RAIN AND LAST THREE DAYS OF RAIN OR IRRIGATIONS
PRINT REGIONAL DATA AND DATA FOR EACH FARM AND FIELD
STOP

Figure A-1. Sequence of computer operations.

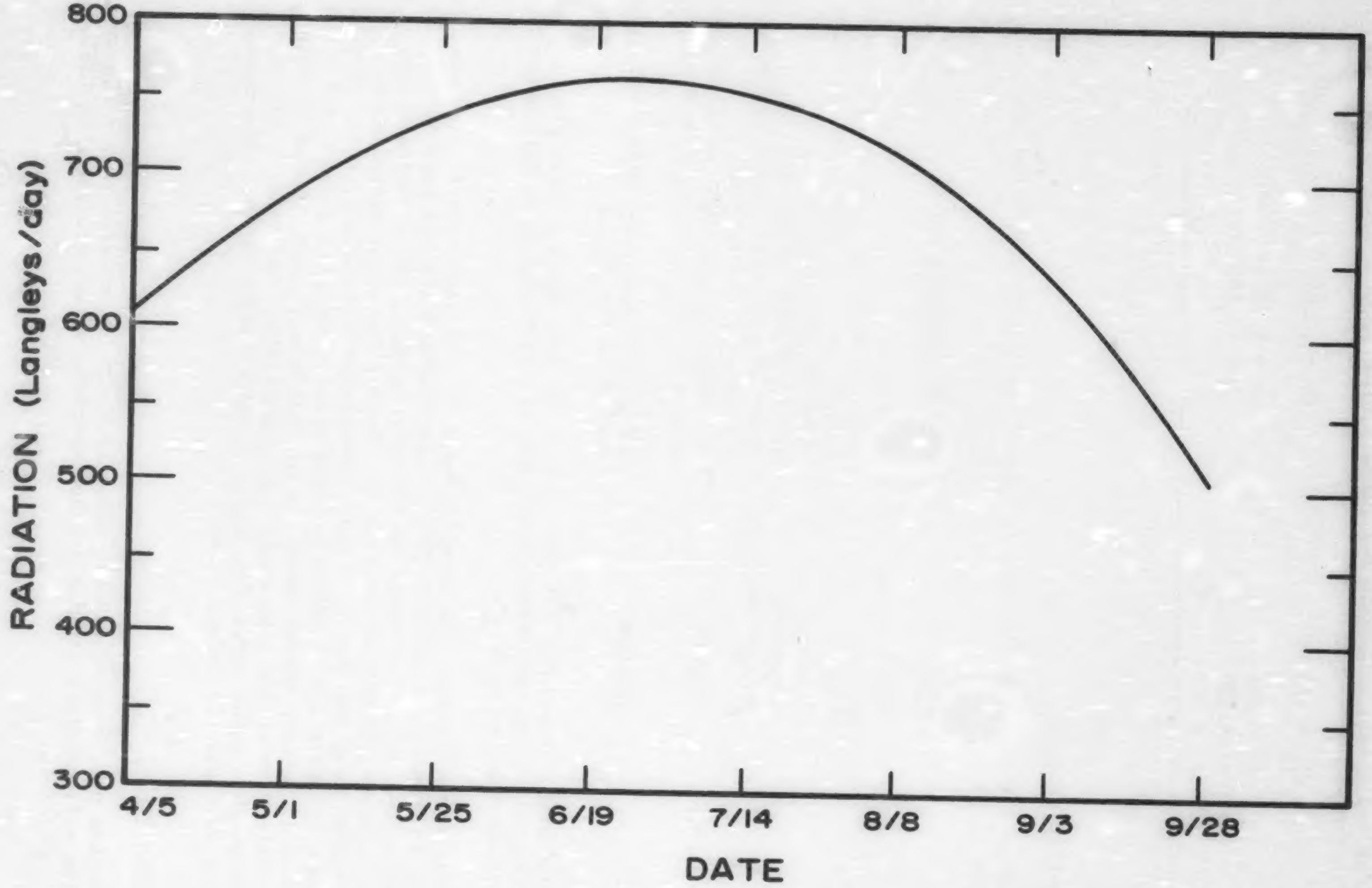

Figure A-2. Clear day solar radiation for Vernal, Utah, irrigation season.

TABLE A-2. AREA CONSTANTS FOR VERNAL, UTAH

E'_{tp} = .33 in.

CW = .0185

t' = 211

t (before) = 120

5 (after) = 63

a = 1.22

b = -0.18

Crop Coefficients

The program contains coefficients for third order polynomials for the following crops.

No.	Crop	100% effective cover
1	Small grains	at heading
2	Beans	bloom or about 50 days after planting
3	Peas	full bloom or 70 days after planting
4	Potatoes	about 80 days after planting
5	Sugarbeets	about 110 days after planting
6	Corn or sorghum	about 10 days after tasseling on corn and heading for sorghum
7	Alfalfa	all season except 30 days after growth begins in the spring and 20 days after cuttings
8	Pasture	all season except 30 days after growth begins in the spring

The coefficients represent two portions of the crop curve: from planting to effective full cover expressed as percent, and from effective full cover to harvest expressed as days.

For alfalfa and pasture, the growing season begins when mean air temperature reaches and remains above 41°F (5°C). Also for alfalfa, by setting the 100 percent effective cover data equal to the cutting date, the adjustment for cutting effects are made automatically. Curves for other crops can be approximated assuming that $K_c = 0.15$ from planting until emergence, it then increases to about 1.0 at effective full cover (leaf area index = 3.5 - 4.0, or about 90 percent ground cover, or at full bloom), and remains at this value until harvest for some crops like sugarbeets. For other crops it remains at this value until they begin to mature after which it decreases to about 0.15 shortly before harvest.

Allowable Depletions

Approximate percentage available water that can be depleted from soils by the time the soil moisture tension reaches specific values are given in Table A-3.

Guides to allowable soil moisture depletions for a medium textured soil are given in Table A-4. These should be used only as an initial guide and in lieu of local experimental data. For deep rooted crops a reference soil sample in the spring is highly desirable. For many shallow rooted crops in winter precipitation areas the soil can be assumed to be at field capacity at planting.

TABLE A-3. APPROXIMATE AMOUNTS OF AVAILABLE WATER THAT CAN BE DEPLETED FROM THE SOILS BY THE TIME THE SOIL MOISTURE TENSION REACHES THE VALUES INDICATED. Adapted from Haise and Hagan (1967)

Soil Moisture Tension	Percentage of available water depleted in:				
	Loamy Sand	Fine Sandy Loam	Sandy Loam	Loam	Clay
Atmospheres	Percent	Percent	Percent	Percent	Percent
0.5	70	65	57	30	13
1.0	82	75	68	57	27
2.0	89	83	78	72	46
5.0	95	92	89	87	73
10.0	99	98	97	95	91

TABLE A-4. GUIDES TO ALLOWABLE SOIL DEPLETION ON A DEEP, MEDIUM TEXTURED SOIL.[1]

No.	Crop	Approximate allowable depletion, inches		
		1st	2nd	other irrigations
1	Small grains	3.0	3.5	4.5
2	Beans	1.7	2.0	2.0
3	Peas	2.5	3.0	3.0
4	Potatoes[2]	1.5	2.0	2.0
5	Sugarbeets	2.5	3.0	3.5
6	Corn or Sorghum	2.5	3.0	3.0
7	Alfalfa	6-8	6-8	6-8
8	Pasture	3.0	3.5	3.5

---

[1] In general, the allowable depletion prior to harvest can approach the maximum available water for crops such as small grains, corns and sorghum. Desirable soil moisture levels at harvest must be considered for potatoes and sugarbeets.

[2] These values may need to be reduced significantly on coarse-textured soils to avoid poorly shaped potatoes.

Variables used in irrigation scheduling program

CODE VARIABLE

A(I,J) = Name of region
AIR = Amount of irrigation water needed
AIRR = Date last irrigation
AJJ5 = Julian day representing the next 5 days
AKC = Crop coefficient adjusted for available soil moisture
AKC1 = Crop coefficient (average based on observed values)
AKC5 = Expected crop coefficient next 5 days (soil moisture not limiting)
AV = Percentage available soil moisture remaining
AVM = Maximum available soil moisture for the soil and crop
AVW = Available water (DPA - DPL)
AV3 = 1.0 + AV

B = Rainfall probability coefficients

C = Coefficients of crop curve polynomials
CRØP = Name of crop and field
CTR = Rough crop coefficient (Jensen-Haise)
CW = Windspeed coefficient (combination equation)

D = Crop coefficient (lower limits)
D1 = Crop coefficient (upper limits)
DATE = Date
DESC = Name of farm
DPA = Depletion allowed
DPL = Soil moisture depletion
DT = Days after NDE
DT1 = Constant in mean potential ET equation, days, before t'
DT2 = Constant in mean potential ET equation, days after t'

E = Irrigation efficiency
ET = Daily evapotranspiration
ETA = Future expected daily ET
ETAP = Mean maximum daily ET for the region
ETA5 = Expected ET next 5 days (soil moisture not limiting)
EØ = Potential ET (Combination method)
ETP = Potential ET (Jensen-Haise)
ETP5 = Potential ET next 5 days
ETR = Increase in ET due to wet soil caused by rain or irrigation

FCT = Forecast potential ET for next 5 days relative to mean (1.0 = normal)
FØRC = Forecast
G = Soil heat flux (estimated)

I = Region number
II,JJ = Julian day
IID,NID = Day number of a month
J = Day number

L = Farm number (used as a loop index in subroutine SCHED)
LF = Leaching fractions
LFZ = Adjusted leaching fraction
LL = Number of farms in a region

M = N + 3
MBD = First Julian day of forecast period (NDB + N)
MN = Month number
MØN = Name of month, MØN(1) = JAN, etc, MØN(13) = None

N = Days of input climatic data
N5 = Day of irrigation within the computation period
NCR = Crop number
NCRØPS = Number of individual crops
ND = Julian day
NDB = Beginning day
NDE = Date of effective cover
NDH = Date of harvest
NDP = Date of planting
NF = Field number in farm L
NFN = Number of fields in farm L
NREG = Number of regions
NXD = Julian date of next irrigation (no rainfall)
NXDP = Julian date of next irrigation (with expected rainfall)

PAMT = Probable amount of precipitation within specified time period
PCT = Stage of growth (planting to effective cover)
PP = Probable precipitation in next 2 weeks

R = Rainfall, daily
RLØ = Net longwave radiation on clear days
RN = Net radiation
RS = Solar radiation
RSØ = Cloudless day solar radiation
RX = Temporary rain amount

SUMR = Sum of rainfall

TAVG = (TMN + TMX)/2
TAX = Maximum temperature, °K/100
TD = Dew point, °F
TEN = Minimum temperature, °K/100
TMN = Minimum temperature, °F
TMX = Maximum temperature, °F
TP = Day of mean maximum, ET, t'
TXR = Constant for region (Jensen-Haise)
T = Time in days for expected precipitation
T1 = Weighting term in combination equation
T2 = Weighting term in combination equation

UA = Average windspeed, mph

VP = Average saturation vapor pressure, mb
VPD = Saturation vapor pressure at dew point, mb
VPSI = Saturation vapor pressure at TMX, mb
VPS2 = Saturation vapor pressure at TMN, mb

W = Daily wind run, miles
WK = Week number (1 = March 1)

X(1,I,J) = TMN
X(2,I,J) = TMX
X(3,I,J) = RS
X(4,I,J) = TD
X(5,I,J) = W
X(6,I,J) = TAVG
X(7,I,J) = ETP
X(8,I,J) = UA
X(9,I,J) = VP
X(10,I,J) = VPD
X(11,I,J) = G
X(12,I,J) = TEN
X(13,I,J) = TAX
X(14,I,J) = RL0
X(15,I.J) = RN
X(16,I,J) = E0

Modified Jensen computer program listing

```
      COMMON A(4,5),CTR(4),TXR(4),ND(4,15),X(16,4,15),DESC(5),DATE(4),
     *CROP(3),AIRR(2),FDRC(15),N(4),NDB(4),RSC(4),W1(7,100),MON(13),IO,
     *NCR,NDE,NDP,C(8,8),B(4,6),ETAP(4),TP(4),DT1(4),DT2(4),FCT(4),ETPS,
     *SUMRT(15),DPLT(15),P(15),SUMR(15),DPL(15)
      DIMENSION CW(4)
      READ(5,1) NREG
    1 FORMAT(5X,I5)
      R(1)=0.0
      R(2)=0.0
      R(3)=0.0
      NF=1
      SUMR(NF)=0.0
      DPL(NF)=0.0
      SUMRT(NF)=0.0
      DPLT(NF)=0.0
      DO 2 I=1,NREG
      READ(5,3)(A(I,J),J=1,5),CTR(I),TXR(I),CW(I)
      READ(5,103) ETAP(I),TP(I),DT1(I),DT2(I)
    2 READ(5,104) B(I,1),B(I,2),B(I,3),B(I,4),B(I,5),B(I,6)
  103 FORMAT(5X,F5.2,3F5.0)
  104 FORMAT(5X,6E10.2)
    3 FORMAT(5X,5A4,2F7.3,F7.4)
      X(1,1,1)=32.
      X(1,1,2)=36.
      X(1,1,3)=34.
      X(2,1,1)=66.
      X(2,1,2)=73.
      X(2,1,3)=69.
      MON(1)='JAN'
      MON(2)='FEB'
      MON(3)='MAR'
      MON(4)='APR'
      MON(5)='MAY'
      MON(6)='JUNE'
      MON(7)='JULY'
      MON(8)='AUG'
      MON(9)='SEPT'
      MON(10)='OCT'
      MON(11)='NOV'
      MON(12)='DEC'
      MON(13)='NONE'
   19 DO 7 I=1,NREG
      READ(5,11)N(I),NDB(I),FCT(I),RSO(I)
      IF(N(I).EQ.0) GO TO 999
   11 FORMAT(5X,2I5,F5.1,F5.0)
      K=N(I)+3
      DO 4 J=4,K
      READ(5,5)ND(I,J),X(1,I,J),X(2,I,J),X(3,I,J),X(4,I,J),X(5,I,J)
    4 CONTINUE
    7 CONTINUE
      WRITE(6,9)
    9 FORMAT(1H1)
    5 FORMAT(5X,I5,5F5.0)
      DO 6 I=1,NREG
      CALL EVAP(I,K)
      CALL VAPOR(I,K,CW)
    6 CALL PRINTR(I,K)
      CALL FARMS(NREG,M1,M2,M3,M4)
      GO TO 19
  999 STOP
      END

END OF COMPILATION:       NO DIAGNOSTICS.
```

```
      SUBROUTINE ETAVG(II,ETA,MBD,I,D,D1,AVM,DPL)
      COMMON A(4,5),CTR(4),TXR(4),ND(4,15),X(16,4,15),DFSC(5),DATE(4),
     +CROP(3),AIRR(2),FORC(15),N(4),NDB(4),RSD(4),W1(7,100),MON(13),ID,
     +NCR,NDE,NDP,C(8,8),B(4,6),ETAP(4),TP(4),DT1(4),DT2(4),FCT(4),ETP5,
     +SUMRT(15),DPLT(15),R(15),SDMR(15)
      DIMENSION D(8),D1(8)
      AI=II
      AV=(1.0-(DPL+ETA)/AVM)*100.
      IF(AV.GT.0.0)GO TO 300
      AV=0.0
  300 AV3=1+AV
    5 IF(II.GT.NDE)GO TO 2
      AP=NDP
      AE=NDE
      PCT=100.*(AI-AP)/(AE-AP)
      AKC1=C(NCR,1)+C(NCR,2)*PCT+C(NCR,3)*PCT**2+C(NCR,4)*PCT**3
      GO TO 1
    2 DT=II-NDE
      AKC1=C(NCR,5)+C(NCR,6)*DT+C(NCR,7)*DT**2+C(NCR,8)*DT**3
    1 IF(AKC1.LT.D(NCR))AKC1=D(NCR)
      IF(AKC1.GT.D1(NCR))AKC1=D1(NCR)
      IF(II.GT.TP(I)) GO TO 7
      DLT=DT1(I)
      GO TO 8
    7 DLT=DT2(I)
    8 AKC=AKC1*ALOG(AV3)/ALOG(101.0)
      ETA=AKC*(ETAP(I)/(EXP(((AI-TP(I))/DLT)**2)))
      IF(II-MBD.LT.5)ETA=ETA*FCT(I)
      RETURN
      END

      SUBROUTINE PRINTR(I,K)
      COMMON A(4,5),CTR(4),TXR(4),ND(4,15),X(16,4,15),DFSC(5),DATE(4),
     +CROP(3),AIRR(2),FORC(15),N(4),NDB(4),RSD(4),W1(7,100),MON(13),ID,
     +NCR,NDE,NDP,C(8,8),B(4,6),ETAP(4),TP(4),DT1(4),DT2(4),FCT(4),ETP5,
     +SUMRT(15),DPLT(15),R(15),SUMR(15),DPL(15)
      JJ=NDB(I)
      CALL DATEE(JJ,MN,NID,336)
      WRITE(6,10)(A(I,J),J=1,5),MON(MN),NID
   10 FORMAT(1H ,5X,'REGION ',5A4,5X,'BEGINNING DATE=',A4,I3)
      WRITE(6,15)
   15 FORMAT(1H ,'  DAY   TAVG    RS      UA     VPS      VPD     RN       C
     +    ETP      EO')
      WRITE(6,27)
   27 FORMAT(1H )
      DO 20 J=4,K
      WRITE(6,25)ND(I,J),X(6,I,J),X(3,I,J),X(8,I,J),X(9,I,J),X(10,I,J),
     +X(15,I,J),X(11,I,J),X(7,I,J),X(16,I,J)
   20 CONTINUE
   35 WRITE(6,40)ETP5
   40 FORMAT(1H ,'FORECAST POTENTIAL ET NEXT 5 DAYS=',F5.2,///)
   25 FORMAT(1H ,I5,F7.1,F6.0,F6.1,F7.1,F8.1,F7.0,F8.1,2F7.2)
      RETURN
      END


      SUBROUTINE DATEE(II,MN,IID,NDH)
      DIMENSION NND(12)
      DATA NND/0,31,59,90,120,151,181,212,243,273,304,334/
      DO 10 J=2,12
      IF(II.LE.NND(J))GO TO 12
   10 CONTINUE
      J=13
   12 MN=J-1
      IID=II-NND(J-1)
      IF(II.LT.NDH)GO TO 14
      MN=13
      IID=0
   14 RETURN
      END
      SUBROUTINE EVAP(I,K)
      COMMON A(4,5),CTR(4),TXR(4),ND(4,15),X(16,4,15),DESC(5),DATE(4),
     *CROP(3),AIRR(2),FORC(15),N(4),NDB(4),PSO(4),W1(7,100),MON(13),ID,
     *NCR,NDE,NDP,C(8,8),B(4,6),ETAP(4),TP(4),DT1(4),DT2(4),FCT(4),ETP5,
     *SUMRT(15),DPLT(15),P(15),SUMP(15),DPL(15)
      DO 10 J=4,K
      X(6,I,J)=(X(1,I,J)+X(2,I,J))/2.0
   15 X(7,I,J)=CTR(I)*(X(6,I,J)-TXR(I))*X(3,I,J)*0.000673
   10 CONTINUE
      RETURN
      END

END OF COMPILATION:        NO DIAGNOSTICS.
```

```
      SUBROUTINE VAPOR(I,K,CW)
      COMMON A(4,5),CTR(4),TXR(4),ND(4,15),X(16,4,15),DESC(5),DATE(4),
     *CROP(3),AIRR(2),FORC(15),N(4),NDB(4),RSO(4),W1(7,100),MON(13),ID,
     *NCR,NDE,NDP,C(8,8),B(4,6),ETAP(4),TP(4),DT1(4),DT2(4),FCT(4),ETP5,
     *SUMRT(15),DPLT(15),P(15),SUMP(15),DPL(15)
      DIMENSION CW(4)
      DO 30 J=4,K
*DIAGNOSTIC*  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IF(X(4,I,J).EQ.0.0) GO TO 35
      X(8,I,J)=X(5,I,J)/24.0
      VPS1=-0.6959+0.2946*X(2,I,J)-0.005195*X(2,I,J)**2+0.000089*
     *X(2,I,J)**3
      VPS2=-0.6959+0.2946*X(1,I,J)-0.005195*X(1,I,J)**2+0.000089*
     *X(1,I,J)**3
      X(9,I,J)=(VPS1+VPS2)/2.0
      X(10,I,J)=-0.6959+0.2946*X(4,I,J)-0.005195*X(4,I,J)**2+
     *0.000089*X(4,I,J)**3
      X(11,I,J)=(X(6,I,J)-(X(1,I,J-1)+X(2,I,J-1)+X(1,I,J-2)+X(2,I,J-2)+
     *X(1,I,J-3)+X(2,I,J-3))/6.0)*5
      T1=0.041+0.0125*X(6,I,J)-4.534*X(6,I,J)**2/10**5
      T2=0.959-0.0125*X(6,I,J)+4.534*X(6,I,J)**2/10**5
      X(12,I,J)=((X(1,I,J)-32)/1.8+273.)/100.0
      X(13,I,J)=((X(2,I,J)-32)/1.8+273.)/100.0
      Y=X(10,I,J)
      JJ=NDB(I)+J-4
      EMT=0.325+0.045*SIN(30*(JJ/30.0-0.5)*3.1416/180.)
      X(14,I,J)=(EMT-0.044*SQRT(Y))*11.71*(X(13,I,J)**4+X(12,I,J)
     ***4)*0.5
      X(15,I,J)=0.77*X(3,I,J)-(1.22*X(3,I,J)/RSO(I)-0.18)*X(14,I,J)
   30 X(16,I,J)=(T1*(X(15,I,J)-X(11,I,J))+T2*15.36*(0.75+CW(I)*
     *X(5,I,J))*(X(9,I,J)-X(10,I,J)))*0.000673
      AJJ5=NDB(I)+N(I)+3
      IF(AJJ5.GT.TP(I))GO TO 34
      DLT=DT1(I)
      GO TO 341
   34 DLT=DT2(I)
  341 ETP5=(ETAP(I)/(EXP(((AJJ5-TP(I))/DLT)**2)))*FCT(I)
   35 RETURN
      END

END OF COMPILATION:          1 DIAGNOSTICS.
```

```
      SUBROUTINE FARMS(NRFG,M1,M2,M3,M4)


      COMMON A(4,5),CTR(4),TXR(4),WD(4,15),X(16,4,15),DESC(5),DATE(4),
     *CROP(3),AIPR(2),FORC(15),N(4),NDB(4),RSD(4),W1(7,100),MON(17),ID,
     *NCR,NDE,NDP,C(8,8),B(4,6),ETAP(4),TP(4),DT1(4),DT2(4),FCT(4),ETPS,
     *SUMRT(15),DPLT(15),R(15),SUMR(15),DPL(15)
      DIMENSION ET(15),D(8),D1(8)
      REAL LF,LF1,LF2
      DATA D1/1.1,1.1,1.1,1.1,1.1,1.1,1.0,.87/
      DATA NCROPS/8/D/0.1,0.1,0.1,0.1,0.10,0.10,0.1,.87/
      C(1,1)=0.233
      C(1,2)=-1.140E-2
      C(1,3)=4.843E-4
      C(1,4)=-2.893E-6
      C(2,1)=0.212
      C(2,2)=-3.532E-3
      C(2,3)=2.562E-4
      C(2,4)=-1.353E-6
      C(3,1)=0.211
      C(3,2)=-3.067E-3
      C(3,3)=2.470E-4
      C(3,4)=-1.321E-6
      C(4,1)=0.111
      C(4,2)=-3.961E-3
      C(4,3)=2.772E-4
      C(4,4)=-1.574E-6
      C(5,1)=0.111
      C(5,2)=-3.961E-3
      C(5,3)=2.772E-4
      C(5,4)=-1.574E-6
      C(6,1)=0.213
      C(6,2)=-4.276E-3
      C(6,3)=2.756E-4
      C(6,4)=-1.583E-6
      C(7,1)=.25
      C(7,2)=.01087
      C(7,3)=0.0
      C(7,4)=0.0
      C(8,1)=0.25
      C(8,2)=0.01508
      C(8,3)=0.0
      C(8,4)=0.0
      C(1,5)=1.022
      C(1,6)=8.532E-3
      C(1,7)=-7.261E-4
      C(1,8)=4.44E-6
      C(2,5)=1.050
      C(2,6)=-1.12E-4
      C(2,7)=-2.644E-4
      C(2,8)=1.65E-6
      C(3,5)=1.005
      C(3,6)=-1.01E-2
      C(3,7)=9.865E-4
      C(3,8)=-2.21E-5
      C(4,5)=0.889
      C(4,6)=1.667E-3
      C(4,7)=-1.87E-4
      C(4,8)=-1.04E-6
      C(5,5)=0.899
      C(5,6)=0.0
      C(6,5)=0.915
      C(6,6)=1.195E-2
      C(6,7)=-4.698E-4
      C(6,8)=2.75E-6
      C(7,5)=.5
      C(7,6)=.025
      C(7,7)=0.0
      C(7,8)=0.0
      C(8,5)=0.87
      C(8,6)=0.0
      C(8,7)=0.0
      C(8,8)=0.0
      READ(5,14)(DATE(K),K=1,4)
   10 FORMAT(5X,I5)
      N4=1
      F=0.9
      DO 100 I=1,NREG
      WRITE(6,13)(A(I,J),J=1,5)
   13 FORMAT(' REGION ',5A4,//)
   14 FORMAT(5X,15A4)
      READ(5,10)LL
      DO 100 L=1,LL
      READ(5,10)NFN
      READ(5,14)(DESC(K),K=1,5)
      WRITE(6,15)(DESC(K),K=1,5),(DATE(K),K=1,4)
   15 FORMAT(' FARM ',5A4,3X,'DATE OF COMPUTATION ',4A4,8X/)
      WRITE(6,16)
   16 FORMAT(15X,'SOIL MOISTURE DEPLETION  IRRIGATIONS LAST, NEXT + AMOU
     +NT',2X)
      WRITE(6,517)
  517 FORMAT(' CROP-FLD  COEF  TO DATE  OPTIMUM  RATE  LAST  RAIN=0   W
     + RAIN   INS',3X)
   24 DO 110 NF=1,NFN
      READ(5,17)NCR,CROP(1),CROP(2),CROP(3),NDP,NDE,ND4E,AVM,LF
   17 FORMAT(5X,I2,2A3,A2,3I5,3F5.2)
      M=N(I)+3
      NN=N(I)
      READ(5,18)(AIRP(J),J=1,2),AIR,N5,(R(J),J=4,M)
   18 FORMAT(5X,2A3,F4.1,I4,10F4.2)
      AKC=0.0
      PCT=0.0
      DT=0.0
      DO 99 J=4,M
      ET(J)=0.0
      ETR=0.0
      RX=R(J)
      SUMR(NF)=SUMR(NF)+R(J)
      SUMRT(NF)=SUMRT(NF)+R(J)
      IF(J-N5-3)76,75,76
   75 LF1=(SUMRT(NF)-DPLT(NF))/SUMRT(NF)
      IF(LF-LF1)5,6,4
    5 LF2=0.0
      GO TO 7
    6 LF2=LF
      GO TO 7
    4 LF2=(DPLT(NF)/(1-LF)-SUMRT(NF))/(E*AIR)
    7 DPL(NF)=0.0
      SUMR(NF)=0.0
   76 IF(NDB(I)-NCP)108,176,176
  176 IF(NDB(I)-NDH)29,29,108
   29 IF(NDB(I)+J-4-NDE)30,30,31
   30 PCT=100.0*(NDB(I)+J-4-NDP)/(NDE-NDP)
      AKC1=C(NCR,1)+C(NCR,2)*PCT+C(NCR,3)*PCT**2+C(NCR,4)*PCT**3
      IF(AKC1-D1(NCR))231,232,232
  232 AKC1=D1(NCR)
  231 AV=(1.0-DPL(NF)/AVM)*100.0
      IF(AV)130,131,131
  130 AV=0.0
  131 AV3=1.0+AV
      AKC=AKC1*ALOG(AV3)/ALOG(101.0)
      GO TO 32
   31 DT=NDB(I)+J-4-NDE
      AV=(1.0-DPL(NF)/AVM)*100.0
      AKC1=C(NCR,5)+C(NCR,6)*DT+C(NCR,7)*DT**2+C(NCR,8)*DT**3
      IF(AKC1-D(NCR))98,235,235
  235 IF(AKC1-D1(NCR))242,241,241
  241 AKC1=D1(NCR)
      GO TO 242
   88 AKC1=D(NCR)
  242 IF(AV)233,234,234
  233 AV=0.0
  234 AV3=1.0+AV
      AKC=AKC1*ALOG(AV3)/ALOG(101.0)
   32 ET(J)=AKC*X(16,I,J)
      IF(AKC-F)38,121,121
   38 IF(R(J-1))42,42,43
   43 ETR=0.8*(F-AKC)*X(16,I,J)
      R(J-1)=R(J-1)-ETR
      IF(R(J-1))49,121,121
   49 R(J-2)=R(J-2)+R(J-1)
      R(J-1)=0.0
   45 IF(R(J-2))46,121,121
   46 R(J-3)=R(J-3)+R(J-2)
      R(J-2)=0.0
   40 IF(R(J-3))53,121,121
   53 ETR=ETR+R(J-3)
      R(J-3)=0.0
      GO TO 121
   42 IF(R(J-2))44,44,47
   47 ETR=0.5*(F-AKC)*(X(16,I,J))
      R(J-2)=R(J-2)-ETR
      GO TO 45
   44 IF(R(J-3))121,121,48
   48 ETR=0.3*(F-AKC)*X(16,I,J)
      R(J-3)=R(J-3)-ETR
      GO TO 40
  121 IF(ETR)50,51,51
   50 ETR=0.0
   51 ET(J)=ET(J)+ETR
   91 DPL(NF)=DPL(NF)+ET(J)-RX
      DPLT(NF)=DPLT(NF)+ET(J)
      IF(DPL(NF))115,99,99
  115 DPL(NF)=0.0
```

```
   99 CONTINUE
      MBD=NDB(I)+N(I)
      DPA=AIR*E*(1-LF2)
      AVW=DPA-DPL(NF)
      DPLA=DPL(NF)
      CALL SCHED(MBD,AVW,NDH,NXD,NXDP,I,DPLA,AVM,D,D1)
      CALL DATEE(NXD,IX,IY,NDH)
      CALL DATEE(NXDP,JX,JY,NDH)
      IF(NDB(I)+N(I)+3-NDE)250,250,255
  250 PCT=100.0*(NDB(I)+N(I)+3-NDP)/(NDE-NDP)
      AKC5=C(NCR,1)+C(NCR,2)*PCT+C(NCR,3)*PCT**2+C(NCR,4)*PCT**3
      GO TO 260
  255 DT=NDB(I)+N(I)+3-NDE
      AKC5=C(NCR,5)+C(NCR,6)*DT+C(NCR,7)*DT**2+C(NCR,8)*DT**3
  260 IF(AKC5.LT.D(NCR))AKC5=D(NCR)
      IF(AKC5.GT.D1(NCR))AKC5=D1(NCR)
      ETA5=AKC5*ETP5
   63 IF(ABS(B(I,1)).LT.(0.00001))GO TO 65
      WRITE(6,64)CROP,AKC5,DPL(NF),DPA,ETA5,AIRR,MON(IX),IY,
     +MON(JX),JY,AIR
   64 FORMAT(2A4,A2,F4.2,3F8.2,2X,2A3,2X,A4,I3,1X,A4,I3,F6.1,3X)
      GO TO 108
   65 WRITE(6,66)CROP,AKC5,DPL(NF),DPA,ETA5,AIRR,MON(IX),IY,AIRR,T,L
   66 FORMAT(2A4,A2,F4.2,3F8.2,2X,2A3,2X,A4,I3,8X,F6.1,3X,2I2)
  108 CONTINUE
      WRITE(6,2)
    2 FORMAT(1X,/,5X,'DAY IN PERIOD      DAILY ET',/)
      DO 9 J=4,M
      J1=J-3
    9 WRITE(6,1)J1,ET(J)
    1 FORMAT(10X,I2,13X,F4.2)
      WRITE(6,8)SUMRT(NF),DPLT(NF)
    8 FORMAT(5X,'TOTAL WATER APPLIED=',F5.2,/,5X,'CUMMULATIVE ET AS OF
     +LAST DAY =        ',F5.2,/)
      WRITE(6,90)LF2
   90 FORMAT(5X,'ADJUSTED LEACHING FRACTION=',F5.2,/)
      K=0
      K1=M-2
      K2=M
      DO 3 J=K1,K2
      K=K+1
      R(K)=R(J)
      ND(I,K)=ND(I,J)
      X(1,I,K)=X(1,I,J)
      X(2,I,K)=X(2,I,J)
      X(3,I,K)=X(3,I,J)
      X(4,I,K)=X(4,I,J)
      X(5,I,K)=X(5,I,J)
    3 CONTINUE
  110 CONTINUE
      IF(ABS(B(I,1)).LT.(0.00001)) GO TO 100
      WK=(NDB(I)+N(I)-53)/7
      PP=14.*(B(I,1)+B(I,2)*WK+B(I,3)*WK**2+B(I,4)*WK**3+B(I,5)*WK**4
     ++B(I,6)*WK**5)
      IF(PP.LT.0.0)PP=0.0
      WRITE(6,163)PP
  163 FORMAT(/,' PROBABLE RAIN NEXT TWO WEEKS=',F5.2,2X,'INCHES',30X)
  100 CONTINUE
      NDB(1)=N4-1
   81 RETURN
      END
      SUBROUTINE SCHED(MBD,AVW,NDH,NXD,NXDP,I,DPL,AVM,D,D1)
      COMMON A(4,5),CTR(4),TXR(4),ND(4,15),X(16,4,15),DESC(5),DATE(4),
     *CROP(3),AIRR(2),FDRC(15),N(4),NDR(4),RSC(4),W1(7,100),MON(13),ID,
     *NCR,NDE,NDP,C(8,8),B(4,6),ETAP(4),TP(4),DT1(4),DT2(4),FCT(4),ETP5,
     *SUMRT(15),DPLT(15),R(15),SUMR(15)
      DIMENSION D(8),C1(8)
      PAMT(T,WK)=T*(B(I,1)+B(I,2)*WK+B(I,3)*WK*WK+B(I,4)*
     *WK**3+B(I,5)*WK**4+B(I,6)*WK**5)
      IF(AVW.LE.0.0) GO TO 10
      BD=MBD
      ETA=0.0
      DO 1 II=MBD,NDH
      CALL ETAVG(II,FTA,MBD,I,D,D1,AVM,DPL)
      AVW=AVW-ETA
      IF(AVW.LE.0.0) GO TO 2
    1 CONTINUE
      GO TO 12
    2 NXD=II
      NXDP=NXD
      IF(ABS(B(I,1)).LT.0.00001)GO TO 11
      WK=(MBD-53)/7
   16 AI=II
      T=AI-BD
      BD=BD+T
      IF(T.LE.14.)GO TO 15
      BD=BD-T+14.
      T=14.
   15 AVW=AVW+PAMT(T,WK)
      L=II+1
      ETA=0.0
      DO 3 II=L,NDH
      CALL ETAVG(II,FTA,MBD,I,D,D1,AVM,DPL)
      AVW=AVW-ETA
      IF(AVW.LE.0.0)GO TO 4
    3 CONTINUE
      GO TO 13
    4 IF(II-1.EQ.NXDP)GO TO 11
      WK=WK+T/7
      NXDP=II
      GO TO 16
   10 NXD=MBD
      NXDP=NXD
      GO TO 11
   12 NXD=NDH
   13 NXDP=NDH
   11 RETURN
      END

END OF COMPILATION:         NO DIAGNOSTICS.
```

APPENDIX B

CORN YIELDS AS AFFECTED BY SALT AND WATER LEVELS

TABLE B-1. OVEN DRY MATTER YIELD, METRIC TON DRY MATTER/HA

Salt Level	Irrigation level									
	2	4	6	8	10	12	14	16	18	20
					Block 1					
1	8.0	11.5	10.8	6.8	8.7	12.2	9.4	7.3	8.3	9.8
2	11.8	11.2	7.9	6.6	13.9	11.3	8.4	11.3	8.4	8.7
3	7.1	9.5	7.2	9.1	6.2	6.4	6.7	5.3	6.3	8.0
4	6.8	10.8	8.3	4.3	9.6	6.8	5.5	4.2	3.6	4.4
5	8.2	6.8	8.4	4.3	5.0	5.1	4.4	2.3	1.5	3.2
6	6.0	7.3	4.2	6.6	6.1	4.4	3.3	2.7	0.6	1.2
7	7.4	7.4	5.7	5.8	4.5	4.0	2.0	2.1	0.3	1.9
8	4.0	3.6	3.7	3.0	1.3	2.6	1.7	0.9	t	0.1
9	2.6	2.7	1.1	2.0	1.7	0.5	0.4	1.1	0.2	0.0
10	3.3	2.5	1.0	0.9	0.8	2.3	1.4	t	0.0	0.0
					Block 2					
1	10.3	7.6	9.1	8.8	7.9	6.8	8.1	8.7	5.5	6.7
2	7.7	11.9	8.9	6.5	7.8	7.2	5.6	8.5	4.1	3.5
3	7.9	6.3	8.3	7.6	7.8	7.5	7.9	7.3	5.5	4.7
4	7.8	8.4	5.5	7.3	8.1	6.8	5.7	4.6	1.9	5.0
5	6.2	6.2	5.5	5.3	6.2	6.0	5.8	3.9	2.1	4.2
6	6.7	5.5	6.7	2.9	4.2	3.0	2.6	2.6	1.7	2.5
7	6.6	6.8	6.8	5.1	7.1	5.2	3.4	3.4	3.4	2.5
8	4.6	3.8	3.4	3.8	3.6	3.1	1.7	1.3	1.1	1.2
9	4.9	4.4	2.8	2.7	4.0	3.6	1.6	1.0	0.1	0.0
10	2.7	2.1	1.6	1.5	2.1	1.7	0.1	0.4	0.0	0.0
					Block 3					
1	10.4	8.5	10.5	7.8	8.0	9.2	9.1	8.9	4.8	5.6
2	9.9	5.9	10.9	9.4	6.0	8.7	5.1	7.6	8.0	5.6
3	10.6	10.3	7.7	11.4	3.7	8.2	8.9	6.7	4.3	7.6
4	9.5	6.5	7.2	8.3	6.0	5.5	8.4	7.5	3.9	3.0
5	5.9	6.6	4.9	5.8	4.9	2.3	3.9	5.5	2.0	3.8
6	7.0	6.2	5.1	4.8	5.4	5.5	3.5	3.2	3.1	1.8
7	5.9	8.2	5.4	4.6	4.0	4.1	3.3	3.3	0.8	3.4
8	4.8	4.8	3.6	4.3	3.0	4.5	4.2	3.1	0.7	0.6
9	2.5	4.3	3.1	3.0	1.7	2.4	2.6	1.1	4.2	0.6
10	2.6	3.0	1.7	0.6	2.8	2.5	1.6	1.1	0.4	0.0

TABLE 59. CONTINUED.

Salt level	Irrigation level									
	2	4	6	8	10	12	14	16	18	20
					Block 4					
1	9.0	10.3	7.6	9.4	10.4	8.5	9.2	9.3	9.7	10.3
2	10.4	10.6	8.4	6.7	12.2	10.3	6.4	11.9	9.1	8.5
3	7.8	9.7	8.9	7.4	9.2	9.0	8.2	9.5	5.7	5.4
4	9.6	10.5	8.5	7.3	7.1	7.8	7.5	8.4	6.9	4.7
5	7.4	7.8	6.6	7.2	6.6	10.2	4.6	6.4	4.5	4.3
6	3.5	8.3	5.7	6.0	6.2	6.8	4.7	5.1	1.8	1.6
7	4.6	7.4	6.2	3.0	5.0	6.2	4.6	4.9	0.9	2.0
8	4.8	6.1	4.5	4.2	3.8	4.2	2.8	2.0	0.2	0.3
9	3.4	3.3	1.6	2.2	2.5	2.0	0.3	1.2	6.5	0.0
10	1.8	4.0	2.5	3.0	2.3	2.7	2.4	0.6	0.3	0.0

TABLE B-2. OVEN DRY MATTER YIELD, GRAMS DRY MATTER/PLANT

Salt level	Irrigation level 2	4	6	8	10	12	14	16	18	20
					Block 1					
1	714	1028	962	609	776	1142	842	654	743	875
2	1049	999	706	586	1242	1007	751	1010	751	778
3	631	846	641	815	552	571	598	475	565	715
4	611	966	740	388	854	607	489	371	320	389
5	816	679	835	431	495	504	440	229	147	321
6	596	725	413	651	605	440	330	266	55	119
7	734	736	569	573	450	396	202	211	28	188
8	596	534	550	440	193	381	248	132	3	14
9	385	409	162	296	252	69	56	14	33	0
10	598	447	183	162	150	225	75	2	0	0
					Block 2					
1	916	677	809	784	702	611	726	780	495	603
2	685	1065	792	578	693	644	503	759	363	314
3	702	561	743	677	693	669	702	652	487	421
4	693	751	495	652	726	611	512	413	173	446
5	619	615	545	525	614	596	570	383	204	420
6	665	546	666	286	415	293	259	258	172	246
7	651	679	671	504	703	516	341	481	340	246
8	688	571	512	416	537	468	252	195	165	179
9	722	660	413	406	592	537	234	144	21	1
10	479	383	281	264	371	297	16	74	0	0
					Block 3					
1	924	759	941	693	718	817	809	792	429	503
2	866	528	974	842	537	776	454	677	718	503
3	949	916	685	1015	330	735	792	594	380	677
4	850	578	644	743	537	491	751	669	347	264
5	587	651	486	578	486	229	385	541	202	376
6	697	614	504	477	532	550	349	321	303	183
7	587	816	532	459	394	404	330	330	83	339
8	715	715	537	647	440	674	619	468	110	83
9	371	647	468	440	254	358	385	165	619	96
10	462	528	301	107	502	446	294	191	78	0

TABLE B-2. CONTINUED

Salt level	Irrigation level 2	4	6	8	10	12	14	16	18	20
					Block 4					
1	801	916	677	842	933	759	825	834	867	916
2	925	949	751	603	1090	916	570	1065	809	759
3	693	867	792	660	817	801	735	850	512	479
4	858	941	759	652	636	693	669	751	619	421
5	734	770	651	715	651	1009	459	633	449	377
6	349	825	569	596	614	679	468	504	183	156
7	459	734	619	293	495	614	459	486	92	202
8	715	908	674	619	571	619	413	299	30	37
9	509	498	234	326	371	296	41	180	963	5
10	330	710	446	537	416	479	426	108	54	0

TABLE B-3. GRAIN YIELD, KG/HA

Salt level	Irrigation level 1	3	5	7	9	11	13	15	17	19
					Block 1					
1	2303	1748	4223	3187	1503	2066	2122	3584	1712	3934
2	1735	1727	1817	1791	5868	1960	2278	1922	1914	3546
3	2836	967	2101	1935	2704	1881	1330	1626	1561	1125
4	1368	2030	1020	2330	2569	981	1254	2075	1857	890
5	319	1606	517	430	760	844	312	264	490	146
6	1016	739	527	575	501	1504	785	46	81	25
7	407	297	943	1255	518	1649	94	885	495	238
8	132	20	559	542	25	199	121	55	0	0
9	11	21	26	14	36	0	0	0	0	0
10	51	141	210	118	101	0	0	0	0	0
					Block 2					
1	2884	2451	2127	2564	3358	1837	2359	1525	3241	3168
2	1372	2666	1094	2650	1734	2941	763	1239	2307	2682
3	763	1191	1934	1934	1084	1191	485	1293	659	1198
4	1292	913	1534	1515	774	1514	1580	1107	210	122
5	1007	1360	1454	740	754	387	765	164	157	158
6	1241	453	440	767	496	305	336	547	246	35
7	300	629	626	1065	1482	561	1766	238	270	174
8	574	76	741	310	706	659	102	0	80	150
9	108	242	406	287	534	358	29	0	0	0
10	106	435	548	232	213	116	29	0	0	0
					Block 3					
1	3165	3733	3147	3358	2295	2534	2984	1761	2874	3679
2	2691	1747	2332	1916	1988	2599	2326	1544	1626	2535
3	2301	2385	2301	2567	878	2452	2177	656	1241	1182
4	1410	1799	1633	1007	805	1447	1859	1541	799	269
5	1584	1370	1015	1149	871	1600	708	646	142	89
6	1474	846	823	426	947	1427	695	30	311	202
7	477	1292	1272	2279	893	904	286	11	587	269
8	334	544	592	252	895	856	320	193	0	9
9	550	407	312	527	703	11	31	9	52	749
10	86	527	5	229	81	160	107	0	0	0

TABLE B-3. CONTINUED

Salt level	Irrigation level 1	3	5	7	9	11	13	15	17	19
					Block 4					
1	1275	2744	2352	2678	1156	1842	2307	1505	1779	3838
2	3867	3431	2019	2497	1510	2616	5118	676	4052	1532
3	3712	1832	1371	798	1549	1221	2357	498	1563	2233
4	2817	2073	1491	2845	1218	1770	2088	1386	1316	803
5	2144	1323	754	1855	1359	1793	1767	1176	634	1326
6	1537	908	1715	951	440	2149	881	90	255	148
7	1592	1170	538	1611	765	1082	80	102	465	183
8	411	510	407	1273	858	704	159	326	435	22
9	42	125	0	91	0	144	0	149	0	0
10	132	333	220	57	104	10	0	0	0	0

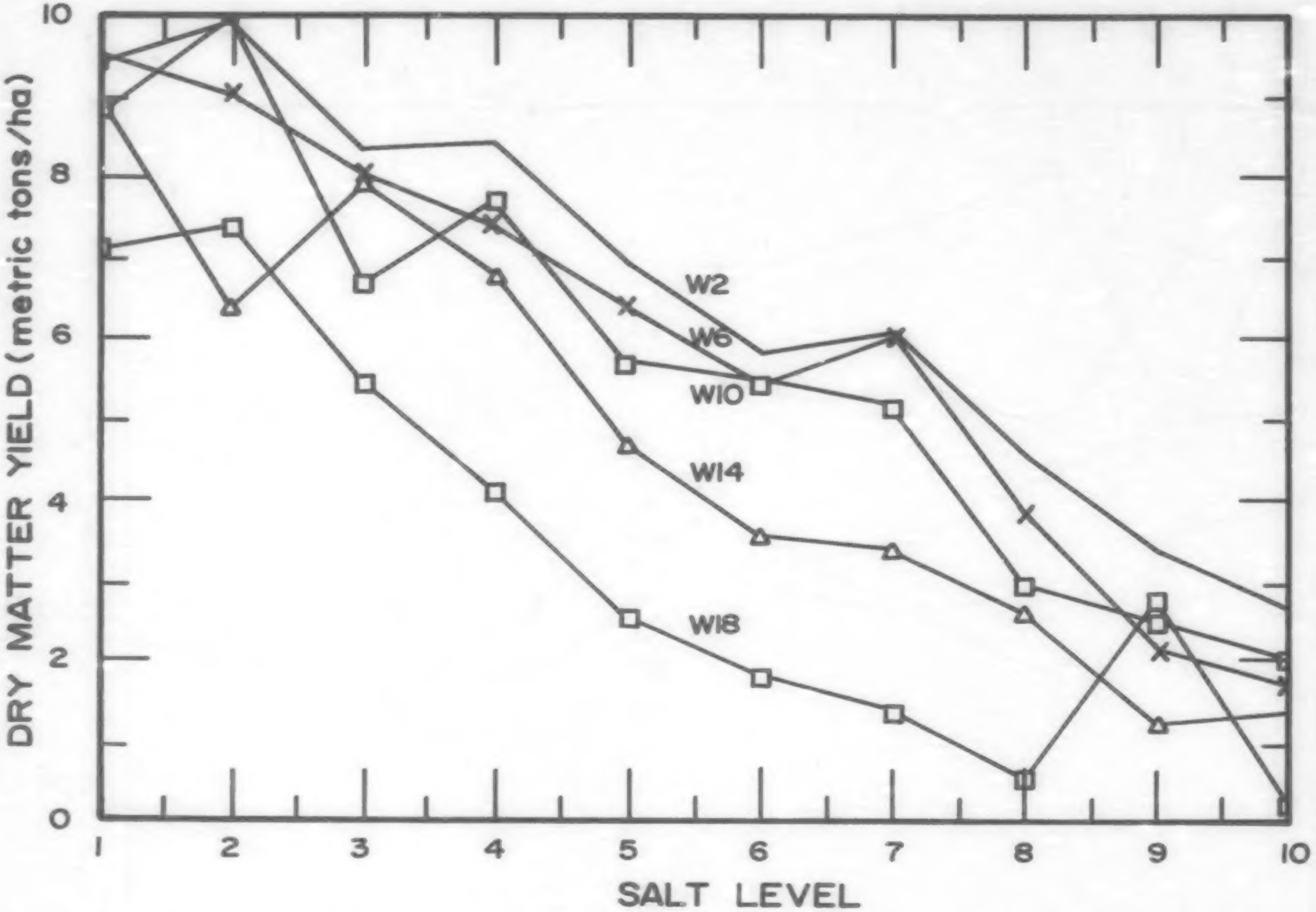

Figure B-1. Dry matter yields as influenced by salt and irrigation levels, metric tons/ha.

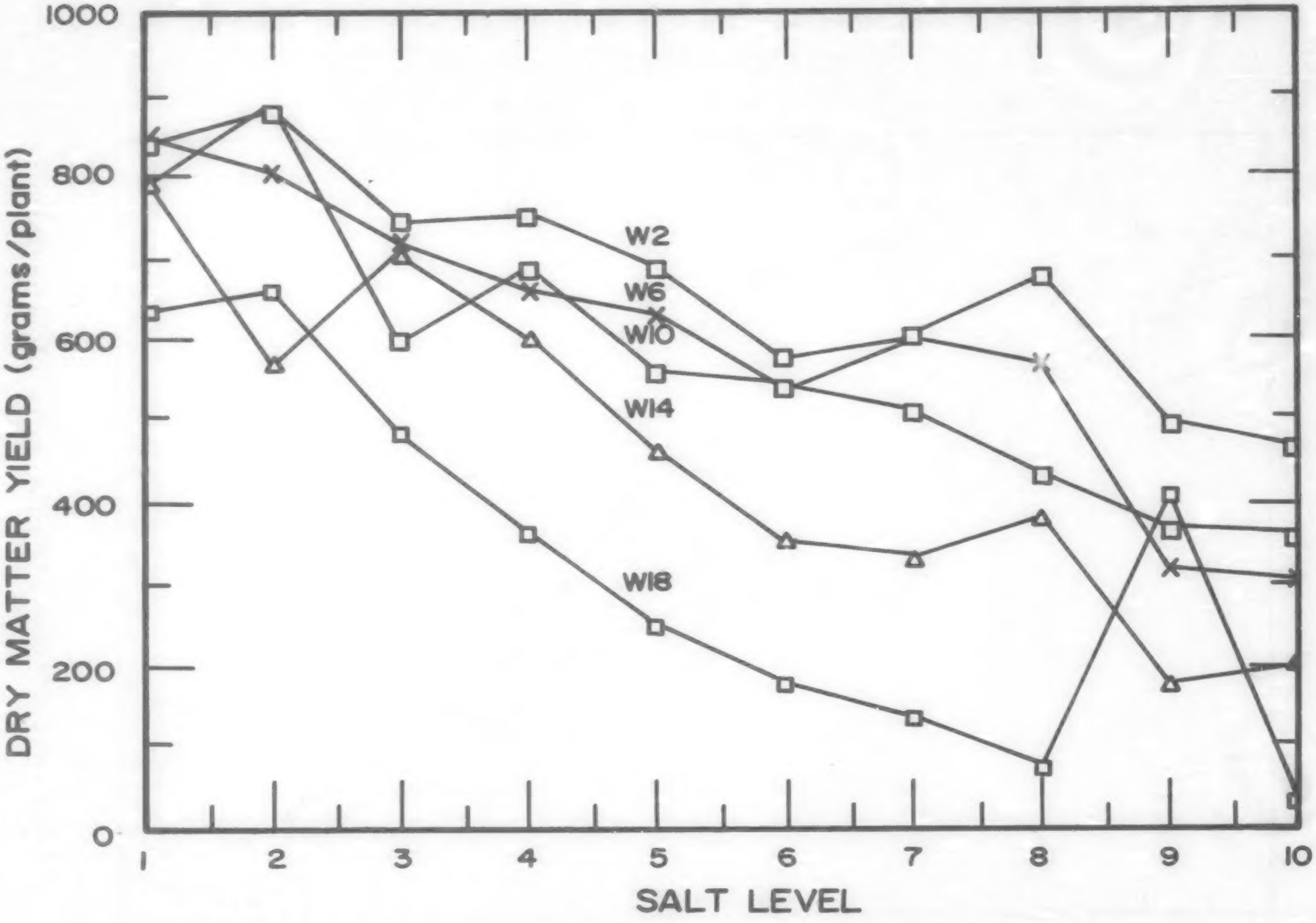

Figure B-2. Dry matter yields in grams/plant as influenced by salt and irrigation levels.

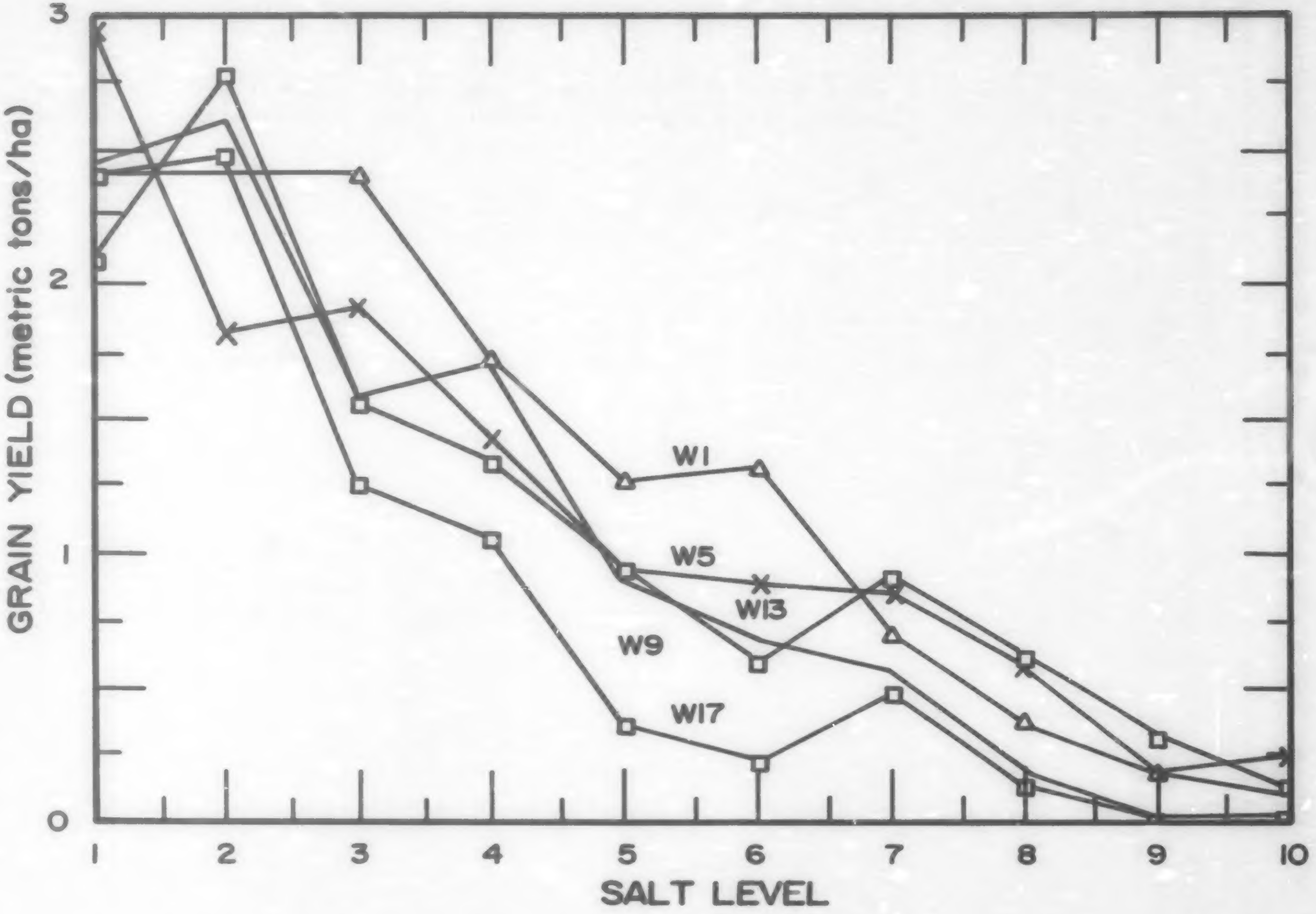

Figure B-3. Grain yields metric tons/ha as influenced by salinity and water levels.

TABLE B-4. ELECTRICAL CONDUCTIVITY OF THE SOIL SOLUTION AS A FUNCTION OF TIME AND SITE, 4-PROBE RESULTS IN MMHOS/CM @ 25°C

Block	Salt level	Water level	Depth inches	Sampling dates 6-12	7-15	8-10	9-18
2	1	19	0-6	0.84	0.42	0.31	0.21
			6-12	0.37	0.21	0.10	0.05
			12-18	0.38	0.14	0.10	0.10
			18-24	0.23	0.18	0.10	0.03
			24-36	0.06	0.06	0.06	0.04
			36-48	0.09	0.10	0.03	0.02
2	1	15	0-6	0.84	0.52	0.42	0.10
			6-12	0.47	0.37	0.21	0.26
			12-18	0.10	0.28	0.21	0.03
			18-24	0.18	0.21	0.16	0.08
			24-36	0.13	0.08	0.15	0.06
			36-48	0.09	0.12	0.05	0.05
2	2	11	0-6	1.98	1.15	0.42	0.31
			6-12	0.16	0.63	0.42	0.31
			12-18	0.38	0.38	0.31	0.21
			18-24	0.29	0.21	0.23	0.21
			24-36	0.23	0.06	0.23	0.08
			36-48	0.12	0.17	0.09	0.10
2	2	7	0-6	1.46	0.84	0.52	0.42
			6-12	0.47	0.37	0.31	0.26
			12-18	0.31	0.77	0.38	0.35
			18-24	0.29	0.08	0.31	0.31
			24-36	0.15	0.21	0.04	0.31
			36-48	0.07	0.05	0.31	0.17
2	3	3	0-6	1.78	0.63	0.42	0.21
			6-12	0.42	0.99	0.52	0.26
			12-18	0.31	0.21	0.14	0.42
			18-24	0.18	0.37	0.31	0.26
			24-36	0.29	0.38	0.44	0.23
			36-48	0.02	0.23	0.28	0.07
3	3	3	0-6	1.25	0.73	0.63	0.21
			6-12	0.52	0.42	0.26	0.31
			12-18	0.35	0.52	0.35	0.29
			18-24	0.29	0.47	0.21	0.26
			24-36	0.21	0.02	0.37	0.27
			36-48	0.03	0.21	0.16	0.14

TABLE B-4. CONTINUED

Block	Salt level	Water level	Depth inches	Sampling dates 6-12	7-15	8-10	9-18
3	4	7	0-6	1.57	0.84	0.21	0.21
			6-12	0.94	0.84	0.42	0.57
			12-18	0.24	0.31	0.59	0.47
			18-24	0.26	0.37	0.23	0.16
			24-36	0.33	0.13	0.17	0.15
			36-48	0.02	0.23	0.31	0.19
3	4	11	0-6	1.36	0.63	0.42	0.21
			6-12	1.20	0.57	0.37	0.37
			12-18	0.56	0.42	0.38	0.49
			18-24	0.03	0.26	0.47	0.47
			24-36	0.73	0.23	0.23	0.10
			36-48		0.24		0.19
3	4	15	0-6	1.15	0.94	0.21	0.42
			6-12	0.84	0.99	0.68	0.52
			12-18	0.66	0.21	0.63	0.24
			18-24	0.23	0.52	0.18	0.21
			24-36	0.19	0.06	0.27	0.13
			36-48	0.17	0.05	0.17	0.12
3	5	19	0-6	1.04	1.46	0.94	0.63
			6-12	1.36	0.52	0.47	0.73
			12-18	0.17	0.45	0.52	0.31
			18-24	0.21	0.31	0.18	0.39
			24-36	0.21	0.04	0.04	0.39
			36-48		0.17	0.12	0.00
2	10	19	0-6	4.70	3.13	3.03	2.30
			6-12	1.10	1.98	1.36	1.78
			12-18	0.91	0.59	0.66	0.77
			18-24	0.05	0.26	0.26	0.08
			24-36	0.04	0.21	0.21	
			36-48		0.00	0.00	0.84
2	10	15	0-6	3.97	2.51	2.72	1.78
			6-12	1.20	2.66	0.99	1.88
			12-18	0.31	1.22	1.36	0.38
			18-24	0.21	0.91	0.05	0.29
			24-36	0.29	0.00	0.02	0.27
			36-48	0.05	0.00	0.00	

TABLE B-4. CONTINUED

Block	Salt level	Water level	Depth inches	Sampling dates 6-12	 7-15	 8-10	 9-18
2	9	11	0-6	5.22	2.82	2.61	2.19
			6-12	0.84	2.14	0.26	0.52
			12-18	0.80	1.08	1.57	1.25
			18-24		0.99	0.13	0.08
			24-36	0.68	0.00	0.94	0.44
			36-48	0.14	0.00	0.00	
2	9	7	0-6	5.22	1.36	2.09	0.21
			6-12	0.63	2.72	1.04	0.78
			12-18	0.77	1.14	1.39	0.66
			18-24	0.18	1.25	0.13	0.16
			24-36	0.50	0.00	0.94	0.19
			36-48		0.00	0.00	0.19
2	8-9	3	0-6	5.64	0.52	0.21	0.94
			6-12	0.21	0.42	0.47	0.21
			12-18	0.94	2.16	1.36	0.97
			18-24	0.44	1.17	2.09	0.08
			24-36	0.06	0.00	0.00	0.86
			36-48	0.03	0.00	0.00	0.00
3	8	3	0-6	1.15	0.84	0.21	0.21
			6-12	1.46	1.51	0.42	0.47
			12-18	1.08	1.01	0.70	0.59
			18-24	0.13	0.75	0.37	0.16
			24-36	0.13	1.19	0.65	0.17
			36-48	0.31	0.00	0.00	0.17
3	8	7	0-6	1.46	0.84	0.21	0.10
			6-12	1.51	1.88	0.47	0.47
			12-18	0.97	0.35	1.46	1.01
			18-24	0.08	0.63	0.03	0.26
			24-36	0.21	0.92	0.88	0.06
			36-48	0.17	0.00	0.00	0.40
3	7	11	0-6	1.25	0.63	0.31	0.21
			6-12	1.20	1.10	0.63	0.37
			12-18	0.97	0.77	0.52	1.32
			18-24	0.23	0.44	0.57	0.03
			24-36	0.23	1.02	0.50	0.08
			36-48	0.10	0.00	0.16	0.45

TABLE B-4. CONTINUED

Block	Salt level	Water level	Depth inches	Sampling dates			
				6-12	7-15	8-10	9-18
3	7	15	0-6	1.46	0.73	0.84	0.10
			6-12	1.20	1.15	1.41	1.62
			12-18	0.45	0.70	0.24	0.24
			18-24	0.47	0.55	0.55	0.13
			24-36	0.19	0.00	0.33	0.29
			36-48	0.16	0.00	0.14	0.07
3	7	19	0-6	2.82	1.36	1.36	1.15
			6-12	0.78	1.20	0.68	1.20
			12-18	0.49	1.36	0.59	0.17
			18-24	0.23	1.01	0.21	0.34
			24-36	0.13	0.00	0.56	0.17
			36-48	0.09	0.00	0.02	0.16
4	1	19	0-6	0.63	0.42	0.21	0.10
			6-12	0.21	0.31	0.16	0.10
			12-18	0.35	0.10	0.17	0.17
			18-24	0.26	0.31	0.16	0.21
			24-36	0.13	0.21	0.13	0.19
			36-48	0.12	0.09	0.09	0.21
4	1	15	0-6	0.73	0.42	0.21	0.21
			6-12	0.26	0.26	0.16	0.16
			12-18	0.38	0.28	0.17	0.28
			18-24	0.21	0.21	0.08	0.10
			24-36	0.15	0.31	0.21	0.17
			36-48	0.10	0.00	0.12	0.16
4	2	11	0-6	0.52	0.42	0.21	0.21
			6-12	0.37	0.26	0.26	0.21
			12-18	0.14	0.28	0.17	0.21
			18-24	0.21	0.13	0.10	0.16
			24-38	0.17	0.27	0.21	0.08
			36-48	0.09	0.00	0.09	0.19
4	2	7	0-6	0.94	0.31	0.21	0.10
			6-12	0.37	0.31	0.21	0.26
			12-18	0.28	0.24	0.24	0.14
			18-24	0.29	0.29	0.23	0.26
			24-36	0.92	0.33	0.36	0.08
			36-48	0.16	0.07	0.00	0.16

TABLE B-4. CONTINUED

Block	Salt level	Water level	Depth inches	Sampling dates 6-12	7-15	8-10	9-18
4	2	3	0-6	0.73	0.42	0.21	0.21
			6-12	0.42	0.42	0.26	0.21
			12-18	0.17	0.28	0.17	0.28
			18-24	0.29	0.39	0.03	0.16
			24-36	0.10	0.04	0.21	0.06
			36-48	0.10	0.07	0.12	0.33
1	3	3	0-6	0.63	0.31	0.21	0.10
			6-12	0.52	0.52	0.16	0.10
			12-18	0.24	0.35	0.28	0.17
			18-24	0.23	0.29	0.18	0.21
			24-36	0.29	0.21	0.17	0.27
			36-48	0.03	0.12	0.31	0.12
1	3	7	0-6	0.63	0.31	0.21	0.10
			6-12	0.42	0.36	0.26	0.21
			12-18	0.45	0.63	0.38	0.31
			18-24	0.42	0.23	0.31	0.39
			24-36	0.15	0.02	0.23	0.29
			36-48	0.12	0.00	0.23	0.16
1	3	11	0-6	1.46	0.73	0.42	0.21
			6-12	0.37	0.89	0.37	0.38
			12-18	0.45	0.42	0.49	0.56
			18-24	0.29	0.63	0.16	0.29
			24-36	0.19	0.02	0.23	0.23
			36-48	0.16	0.09	0.28	0.00
1	4	15	0-6	2.30	0.94	1.04	0.73
			6-12	0.57	1.31	0.52	0.16
			12-18	0.59	0.38	0.80	0.87
			18-24	0.23	0.37	0.00	0.05
			24-36	0.13	0.17	0.00	0.21
			36-48	0.03	0.00	0.00	0.00
1	4	19	0-6	1.98	1.25	0.94	0.63
			6-12	0.57	0.73	0.42	0.26
			12-18	0.66	0.45	0.49	0.38
			18-24	0.21	0.29	0.13	0.16
			24-36	0.17	0.21	0.19	0.17
			36-48	0.00	0.00	0.03	0.07

TABLE B-4. CONTINUED

Block	Salt level	Water level	Depth inches	Sampling dates 6-12	7-15	8-10	9-18
4	6	19	0-6	1.36	1.25	0.94	0.10
			6-12	0.57	0.63	0.57	1.25
			12-18	0.52	0.49	0.80	0.49
			18-24		0.08	0.00	0.10
			24-36	0.63	0.21	0.00	0.23
			36-48	0.12	0.00	0.00	0.12
4	6	15	0-6	2.40	0.84	1.25	0.73
			6-12	0.31	1.04	0.42	0.31
			12-18	0.91	0.24	0.87	0.73
			18-24	0.34	1.28	0.78	0.00
			24-36	0.00		0.00	0.44
			36-48	0.21		0.00	
4	7	11	0-6	1.36	0.42	1.67	0.42
			6-12	0.63	0.94	0.37	0.21
			12-18	0.84	0.31	1.08	0.59
			18-24	0.21	0.70	0.10	0.29
			24-36	0.56		0.00	0.59
			36-48		0.57	0.00	
4	7	7	0-6	1.57	0.31	1.36	0.10
			6-12	0.26	0.68	0.16	0.26
			12-18	1.04	0.45	0.73	0.31
			18-24	0.31	0.76	0.26	0.21
			24-36	0.31	0.00	0.06	0.33
			36-48		0.10	0.00	0.03
4	8	3	0-6	1.67	0.63	0.94	0.31
			6-12	1.41	0.99	0.78	0.42
			12-18	1.11	0.49	0.10	0.49
			18-24	0.13	0.31	0.26	0.18
			24-36	0.40		0.90	0.71
			36-48	0.00		0.52	0.00
1	8	3	0-6	3.34	0.94	2.09	0.21
			6-12	1.10	1.41	0.52	0.21
			12-18	0.56	0.52	0.00	0.38
			18-24	0.23	0.68	0.52	0.26
			24-36	0.13	0.13	0.71	0.36
			36-48	0.04	0.12	0.00	0.05

TABLE B-4. CONTINUED

				Sampling dates			
Block	Salt level	Water level	Depth inches	6-12	7-15	8-10	9-18
1	9	7	0-6	5.74	3.34	1.15	0.94
			6-12	0.63	1.25	1.46	0.68
			12-18	0.73	0.49	1.81	0.97
			18-24	0.39	0.89	0.00	0.29
			24-36	0.10	0.29	0.00	0.61
			36-48	0.21	0.12	0.00	0.26
1	9	11	0-6	8.56	2.61	2.51	0.21
			6-12		2.19	2.25	2.25
			12-18	0.26	0.59	0.00	1.50
			18-24	0.37	0.26	0.00	0.47
			24-36	0.19	0.23	0.00	0.40
			36-48	0.52	0.70	0.00	0.00
1	10	15	0-6	5.64	4.07	3.55	0.21
			6-12	0.84	1.98	0.99	2.51
			12-18	0.59	0.00	1.43	0.35
			18-24		0.13	0.00	0.34
			24-36	0.83	0.04	0.00	0.44
			36-48		0.17	0.00	0.10
1	10	10	0-6	4.28	2.82	2.82	2.51
			6-12	0.89	1.72	2.77	1.20
			12-18	0.80	0.17	0.00	0.56
			18-24	0.21	0.39	0.00	0.18
			24-36	0.46	0.08	0.00	0.42
			36-48		0.19	0.00	0.00

TABLE B-5. ELECTRICAL CONDUCTIVITY OF WATER SAMPLES EXTRACTED FROM CERAMIC CUPS, MMHOS/CM @ 25°C

Block	Salt level	Water level	Sampling dates 6-13	7-9	7-17	8-1	8-12	8-27	9-18
2	1	19		5.3	5.8	5.6			
	1	15			5.2	5.2	5.8		
	2	11		4.8	2.7		5.3	7.0	7.6
	2	7	5.5	4.3	5.5	5.7	5.9	7.5	7.3
	3	3	4.7						
3	3	3	4.4	3.8					
	4	7	7.3	3.4	2.6	3.6			
	4	11		3.8			4.2		
	4	15	5.2		6.8	5.19	4.8		
	6	17	3.4	3.7	3.6	3.6	3.3	4.8	3.7
	6	13	6.8	4.2	4.2		4.2	4.3	
	6	9	4.4	4.8	3.3		4.9	5.8	
	6	5	4.9	2.2	2.8	3.4	3.8	4.3	5.1
	6	1	4.3		5.5	13.2	15.2	8.2	15.6
2	6	5	4.3	3.2	3.4		4.6	5.3	6.3
	6	9		4.3	4.6				
	6	13							
	6	17	3.7	3.4	4.4	5.0	6.7	7.8	
	10	19	16.7	8.4	4.2	6.0	6.1		19.2
	10	15	10.9	12.3			7.8		7.1
	9	11	14.6	24.6	7.7		7.7		8.2
	9	7		2.6					
	8-9	3	3.7	4.6			10.3		12.3
3	8	3	3.6	3.6	3.5	3.7	4.1	4.8	6.6
	8	7	4.6	4.1			4.2	4.3	4.2
	7	11	5.9	5.2			4.7		4.5
	7	15	5.2	5.3	5.2	6.6	6.4		6.4
	7	19	5.5	5.0	5.0	5.0	5.0	4.9	8.0
4	1	19	4.4	4.3	4.3	4.3	4.7		8.8
	1	15		3.8	3.8	3.8	4.1		5.0
	2	11	4.0	3.7		4.2	3.7	3.8	4.3
	2	7	3.4	2.3	3.7		3.2	4.0	4.9
	2	3							

TABLE B-5. CONTINUED

Block	Salt level	Water level	Sampling dates 6-13	7-9	7-17	8-1	8-12	8-27	9-18
1	3	3		5.3	3.2	4.8	5.6	5.8	7.5
	3	7	6.3		4.7	5.6	5.7	4.2	5.1
	3	11	5.2	5.1	4.4	5.2	5.6	7.1	7.7
	4	15		6.0			5.1		5.7
	4	19		5.3		6.4	5.7	7.0	5.8
	5	17			5.6	5.6	6.6	5.5	5.8
	5	13	6.1	5.2		5.4	5.7	7.1	9.7
	5	9	5.2	4.4	5.1	5.6	5.9	8.7	12.7
	5	5	4.9		1.8	6.8	10.3	9.9	9.8
	5	1	5.1	4.8	3.9	6.1	8.1	10.7	11.3
4	5	5	5.4	4.2	5.0	6.4	7.5	8.6	
	5	9	5.7	2.6	2.8	2.3	2.9	3.8	6.4
	5	13	5.8	6.6		8.7	7.7	8.3	
	5	17	3.2	3.7		3.3	3.5	3.4	3.2
	6	19		5.7	6.2	5.1	5.0	4.9	
	6	15	5.4			4.3			
	7	11	6.4	3.5	4.2	3.8	4.3	4.4	4.8
	7	7							15.5
	8	3	6.3	4.7		5.2	7.4	11.0	7.7
1	8	3	5.9		2.6	4.2	4.7	6.4	
	9	7							
	9	11	6.3					5.3	5.6
	10	15	6.7	21.0		10.4	9.4	7.8	6.3
	10	19							

APPENDIX C

A program to compute K for the numerical approximation of:

$$(dc/dt) = D(d^2c/dz^2) - U(dc/dz) + K(R - c)$$

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NOTATION
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C1(I)      CONCENTRATION OF SOIL SOLUTION IN SPACE INCREMENT I
S2(I)      SOLID SALT IN SOIL IN INCREMENT I
C2(I)      CONCENTRATION AFTER ONE TIME INCREMENT
S2(I)      SOLID SALT AFTER ONE TIME INCREMENT
A,B,C      VECTORS IN MATRIX OF COEFFICIENTS
E          VECTOR OF SOLUTIONS
V          REAL VELOCITY  (CM/H)
D          COEFFICIENT OF HYDRODYNAMIC DISPERSION AND DIFFUSION
                                                        (CM**2/H)
R,RK       COEFFICIENTS IN THE BASIC EQUATION
NF,NL      SUBSCRIPTS OF THE FIRST AND THE LAST SPACE GRID POINTS
TH         WATER CONTENT
CIR        CONCENTRATION OF IRRIGATION WATER  (MICROMHOS)
DTI        INITIAL TIME INCREMENT
DT2        VARIABLE TIME INCREMENT
DZ         SPACE INCREMENT  (CM)
STMAX      TOTAL TIME REQUIRED  (H)


    DIMENSION C1(11),S1(11),C2(11),S2(11),A(11),B(11),C(11),E(11)
   1,T(100),ECM(100),ECC(100),ECC1(100),G(51,100),XT(5),SIN(11)
   1,CIN(11)


    READ GENERAL DATA


    READ(5,101)V,D,R,TH,CIR
101 FORMAT(5(4X,E10.5))
    READ(5,103)DTI,DZ,NF,NL,NDATA,BL,CA,CE,AS
103 FORMAT(2(4X,E10.5),3(3X,I3),4A1)

    READ INITIAL CONDITIONS

    READ(5,102)(CIN(I),SIN(I),I=NF,NL)
102 FORMAT(2E10.5)

    READ(5,102)(T(I),ECM(I),I=1,NDATA)
    STMAX=T(NDATA)

    WRITE(6,210)
210 FORMAT(1H1,64X,'K',11X,'SUM(ECC-ECM)**2'//)
```

```
C     COMPUTE A AND C
C
      NFP1=NF+1
      NLM1=NL-1
C
      DO 1 I=NFP1,NL
      A(I)=D/(2.*DZ**2)+V/(4.*DZ)
      C(I)=D/(2.*DZ**2)-V/(4.*DZ)
      IF(I.EQ.NFP1)A(I)=0.
      IF(I .EQ. NL) C(I)=0.
    1 CONTINUE
C
      RK=0.
      DK=.01
      SUMDEV=10.**20.
      NRK=0
   15 M=1
      DO 10 I=1,NL
      C1(I)=CIN(I)
   10 S1(I)=SIN(I)
      DT2=DTI
      NRK=NRK+1
      ST=0.
C
    4 ST=ST+DT2
C
C     COMPUTE B
C
      DO 2 I=NFP1,NLM1
    2 B(I)=(-1.)/DT2-D/DZ**2
C
C     THE SOLUTION IS BY SUB TRIDAG
C
      B(NL)=B(3)+C(3)
C
C     COMPUTE S2
C
      DO 3 I=NF,NL
      S2(I)=S1(I)-RK*(R-C1(I))*DT2
      IF(S2(I).LT.0.)S2(I)=0.
    3 CONTINUE
C
C     COMPUTE VECTOR OF SOLUTIONS
C
      DO 5 I=NFP1,NLM1
      RKS=RK*(R-C1(I))
      IF(S1(I).LT.1.)RKS=0.
      E(I)=((-1.)/DT2)*C1(I)-(D/(2.*DZ**2))*(C1(I+1)-2.*C1(I)+C1(I-1))
     1(V/(4.*DZ))*(C1(I+1)-C1(I-1))-RKS
      IF(I.EQ.NFP1)E(I)=E(I)-CIR*A(3)
    5 CONTINUE
```

```
      RKS=RK*(R-C1(NL))
      IF(S1(I).LT.1.)RKS=0.
      E(NL)=((-1.)/DT2)*C1(NL)-(D/(2.*DZ**2))*(C1(NLM1)-C1(NL))+
     1(V/(4.*DZ))*(C1(NL)-C1(NLM1))-RKS
      CALL TRIDAG (NFP1,NL,A,B,C,E,C2)
      C1(1)=CIR
      C2(1)=CIR
C
      IF(ABS(ST-T(M)).GT.0.0001)GO TO 12
      ECC(M)=C2(NL)
      M=M+1
   12 DT2=0.1+0.008*ST
      IF(DT2.GT.0.3)DT2=0.3
      IF((ST+DT2).LT.T(M))GO TO 8
      DT2=T(M)-ST
    8 DO 6 I=1,NL
      S1(I)=S2(I)
    6 C1(I)=C2(I)
C
      IF(ST.LT.STMAX)GO TO 4
C
C
      SUMDV1=0.
      SW=0.
      DO 9 I=1,NDATA
      SUMDV1=SUMDV1+(T(I)-SW)*(ECM(I)-ECC(I))**2
    9 SW=T(I)
      WRITE(6,205)RK,SUMDV1
  205 FORMAT(50X,2(10X,E10.5))
C
      IF(SUMDV1.GT.SUMDEV)DK=(-DK)/2.
      IF(ABS(DK).LT.0.000000001)GO TO 11
      IF(NRK.GT.99)GO TO 11
      SUMDEV=SUMDV1
      RK1=RK
      DK=0.
      RK=RK+DK
C
      DO 13 I=1,NDATA
   13 ECC1(I)=ECC(I)
      GO TO 15
C     WRITE GENERAL DATA
C
   11 WRITE(6,201)V,D,R,TH,CIR,DTI,DZ,STMAX,NF,NL
  201 FORMAT(1H1,'GENERAL DATA'//
     11H ,'V     =',E10.5,' (CM/H)'/
     11H ,'D     =',E10.5,' (CM**2/H)'/
     11H ,'R     =',E10.5/
     11H ,'TH    =',E10.5/
     11H ,'CIR   =',E10.5,' (MICROMHOS)'/
     11H ,'DTI   =',E10.5,' (H)'/
     11H ,'DZ    =',E10.5,' (CM)'/
     11H ,'STMAX=',E10.5,' (H)'/
C
     11H ,'NF     =',I5/
     11H ,'NL     =',I5////)
C
C      WRITE INITIAL CONDITIONS
C
       WRITE(6,203)(CIN(I),I=NF,NL),(SIN(J),J=NF,NL)
  203 FORMAT(1H ,45X,'INITIAL CONDITIONS'//
     11H ,'C     ',11E10.5/
     11H ,'S     ',11E10.5)
      WRITE(6,208)RK1
  208 FORMAT(////1H ,'K=',E13.8////)
      WRITE(6,204)
  204 FORMAT(1H1,6X,'TIME (H)     EC MEASURED      EC CALCULATED'/)
      WRITE(6,209)(T(I),ECM(I),ECC1(I),I=1,NDATA)
  209 FORMAT(1H ,3X,E10.5,5X,E10.5,6X,E10.5)
C
      D6=NDATA
      SUMY=0.
      SUMYY=0.
C
      DO 30 I=1,NDATA
   30 SUMY=SUMY+ECM(I)
      AVY=SUMY/D6
      TOTVAR=0.
      SW=0.
      DO 31 I=1,NDATA
      TOTVAR=TOTVAR+(T(I)-SW)*(ECM(I)-AVY)**2
   31 SW=T(I)
      IF(SUMDV1.GT.TOTVAR)GO TO 20
      COR=SQRT(1.-SUMDV1/TOTVAR)
      WRITE(6,211)COR
  211 FORMAT(/// ,10X,'COEFFICIENT OF CORRELATION= ',F6.4)
C
C     PLOT
C     ---
C
   20 DO 21 I=1,51
      DO 21 J=1,100
   21 G(I,J)=BL
C
      YMAX=0.
      YMIN=10.**10.
      DO 22 I=1,NDATA
      IF(ECM(I).GT.YMAX)YMAX=ECM(I)
      IF(ECM(I).LT.YMIN)YMIN=ECM(I)
      IF(ECC1(I).GT.YMAX)YMAX=ECC1(I)
      IF(ECC1(I).LT.YMIN)YMIN=ECC1(I)
   22 CONTINUE
C
      SCALEX=STMAX/100.
      SCALEY=(YMAX-YMIN)/50.
      DO 23 I=1,NDATA
      IX=T(I)/SCALEX
      IYC=51.-(ECC1(I)-YMIN)/SCALEY
      IYM=51.-(ECM(I)-YMIN)/SCALEY
C
      G(IYC,IX)=CA
      G(IYM,IX)=CE
      IF(IYC.EQ.IYM)G(IYM,IX)=AS
   23 CONTINUE
C
      WRITE(6,501)
  501 FORMAT(1H1,30X,'MEASURED AND COMPUTED VALUES OF EC VS. TIME'/)
  502 FORMAT(1H ,E10.5,' +',100A1)
  503 FORMAT(1H ,11X,'I',100A1)
  504 FORMAT(1H ,11X,'-',5(19('-'),'+')/
     11H ,16X,5(10X,E10.5))
C
      DO 24 I=1,41,10
      AI=I
      Z1=YMAX-(YMAX-YMIN)*(AI-1.)/50.
      WRITE(6,502)Z1,(G(I,K),K=1,100)
      L1=I+1
      L9=I+9
   24 WRITE(6,503)((G(N1,N2),N2=1,100),N1=L1,L9)
      WRITE(6,502)YMIN,(G(51,N3),N3=1,100)
C
      DO 25 I=1,5
      AI=I
   25 XT(I)=T(NDATA)*(AI/5.)
      WRITE(6,504)(XT(I),I=1,5)
      STOP
      END



      SUBROUTINE TRIDAG(NF,NL,A,B,C,D,V)
      DIMENSION A(NL),B(NL),C(NL),D(NL),V(NL),BETA(101),GAMA(101)
      BETA(NF)=B(NF)
      GAMA(NF)=D(NF)/BETA(NF)
      NFP1=NF+1
      DO 1 I=NFP1,NL
      BETA(I)=B(I)-A(I)*C(I-1)/BETA(I-1)
    1 GAMA(I)=(D(I)-A(I)*GAMA(I-1))/BETA(I)
      V(NL)=GAMA(NL)
      LAST=NL-NF
      DO 2 K=1,LAST
      I=NL-K
    2 V(I)=GAMA(I)-C(I)*V(I+1)/BETA(I)
      RETURN
      END
```

TABLE D-1. LEACHING EXPERIMENTS TO COMPUTE D.

Experiment	6			7			8a			8b		
Column's length (cm)	25			24			24			24		
U (cm/hr)	5.07			3.98			0.98			0.81		
Cir (μmho/cm)	2010			1500			10990			10930		
Cin (μmho/cm)	10190			10200			1650			1680		
Measured and	T	M	C	T	M	C	T	M	C	T	M	C
computed values of	2.19	9608	9548	3,12	8750	8751	11,03	2790	2810	8.97	1680	1742
ECef (mho/cm) Vs.	2.58	9005	9021	3,79	7750	7759	13,51	3690	3693	23,50	5320	5321
time.	3,23	8066	7954	4,10	7350	7327	16,46	4800	4801	25.28	5790	5893
T - Time (hr)	3.68	7150	7184	5.21	5850	5855	19.26	5810	5795	27.60	6590	6590
M - Measured	3.89	6815	6834	5.86	5150	5167	22.05	6700	6680	29.14	7190	7019
C - Computed	4.62	5899	5718	6.39	4550	4571	25.01	7490	7470	31.27	8130	7557
	5.11	5340	5080	7.03	4050	4061	28.89	8330	8330	33.40	8940	8035
	6.55	4290	3711	7.52	3700	3697	34.17	9210	9178	35.91	9940	8527
	7.57	3821	3110	8.02	3300	3324	36.34	9410	9445	38.23	10280	8914
	8.08	3597	2892	8.85	2950	2966	38.21	9610	9642			
	9.39	3195	2508	9.32	2750	2754	42.87	10050	10032			
	11.41	2648	2215	10.20	2450	2445	50.17	10390	10427			

A program to search for the best coefficient of dispersion based on minimizing the sum of the absolute deviation.

```
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION T(12),E(12),C(12)
C
C    GENERAL DATA
C
      D=3.
      DD=1.
C
      READ(5,101)N,X,V,CI,CO
  101 FORMAT(I3,F3.1,F4.2,2F5.0)
      READ(5,102)(T(I),E(I),I=1,N)
  102 FORMAT(F5.3,F5.0)
C
      WRITE(6,204)
  204 FORMAT(1H1,'      D',26X,'SUM OF ABS DEV'///)
      R1=10.**30.
      NK=0
C
    2 EX=DEXP(V*X/D)
C
      DO 1 I=1,N
      VT=V*T(I)
      P=2.*(D*T(I))**0.5
      A1=(X-VT)/P
      B1=(X+VT)/P
      CALL ERFC(A1,A)
      CALL ERFC(B1,B)
    1 C(I)=(1.-0.5*(A+EX*B))*(CO-CI)+CI
C
      R2=0.0
C
      DO 3 I=1,N
    3 R2=R2+ABS(E(I)-C(I))
      IF(R2.GT.R1)DD=DD*(-0.1)
      IF(ABS(DD).LT.0.0002)GO TO 5
      WRITE(6,201)D,R2
  201 FORMAT(1H ,F10.4,20X,E14.7)
      R1=R2
      D=D+DD
      NK=NK+1
      IF(NK.GT.50)GO TO 5
      GO TO 2
    5 WRITE(6,301)X,V,CI,CO,D
  301 FORMAT(1H1,19X,'COMPUTATION OF D'////
     11H0,10X,'L =',F5.1,'  CM'/
     11H0,10X,'V =',F6.2,' CM/HOUR'/
     11H0,10X,'CI=',F7.0,'MICMHO'/
     11H0,10X,'CO=',F7.0,'MICMHO'///
     11H0,10X,'D =',F6.2,' CM**2/H'///)
```

```
      WRITE(6,207)(T(I),I=1,N)
      WRITE(6,203)(E(I),I=1,N)
      WRITE(6,202)(C(I),I=1,N)
  202 FORMAT(1H0,'EC CALCULATED',12F8.0)
  203 FORMAT(1H0,'EC MEASURED  ',12F8.0)
  207 FOPMAT(1H0,'TIME         ',12F8.2)
      AN=N
      SM=0.
      SC=0.
      SCI=0.
      DO 7 I=1,N
    7 SCI=SCI+E(I)
      AVE=SCI/AN
      DO 8 I=1,N
      SC=SC+(C(I)-E(I))**2
    8 SM=SM+(E(I)-AVE)**2
      R=SQRT(ABS(1.-SC/SM))
      WRITE(6,205)R
  205 FORMAT(1H0,'R = ',F6.4)
      STOP
      END



      SUBROUTINE ERFC(X,Y)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      Z=ABS(X)
      IF(Z.GT.4.0)GO TO 1
      SZ=Z
      B=1.0
      DO 3 I=1,50
      AI=I
      B=B*AI
      C=2.*AI+1.0
    3 SZ=SZ+(-1.)**AI*Z**C/(C*B)
      SZ=SZ*1.128379
      GO TO 2
    1 SZ=1.0
    2 IF(X.LT.0.0)SZ=(-SZ)
      Y=1.-SZ
      RETURN
      END
```